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MECHANICAL STOKING OF LOCOMOTIVES.*

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IT gives me more than ordinary pleasure to have this opportunity to speak upon the subject of "Mechanical Stoking of Locomotives" before this audience and under the auspices of The Franklin Institute of the State of Pennsylvania, because those of us in commercial and industrial activities are usually accused of having an ulterior motive when we speak upon the subjects in which we are personally interested, and the privilege of having an audience disinterested from the purely utilitarian standpoint is much appreciated, and I hope to make the subject of interest of itself. I am therefore more than happy to be permitted to speak plainly upon phases of the Locomotive Mechanical Stoker problems, which are ordinarily held in the background, especially so because The Franklin Institute stands committed to encourage the application of mechanical and scientific principles which, by their use in industrial pursuits, may in some measure relieve the stress of physical labor when arduous, conserve energy, or add to the wealth of the individual, community, or nation, by effecting economies in any direction.

I shall therefore try to approach the subject of the evening

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from the point of view of your honored institution, free even from what our legal friends would term "implied bias."

The firing of a steam locomotive with what in common railroad parlance is known as a "scoop" is about as crude a process as can be imagined, and has not changed very much in arrangement or method since locomotives were first used, and I shall take the liberty of assuming your entire familiarity with this hand-firing practice and also the continual increase in the size of locomotives during the past twenty or more years, and will refer mainly to locomotives in general service to-day, rather than to those in use when experiments with mechanical stokers first began.

There are something over three thousand patents on record covering mechanical stokers for locomotives, some of which were intended by the inventors to be suitable for use on stationary boilers as well. This does not include a still greater number of patents taken out on devices in connection with the firing of locomotives and stationary boilers with finely ground or pulverized fuel. This large number of patents will illustrate the difficulty of attempting to give any complete history of the development of the mechanical stoker for locomotives within the limits of this paper, and I shall therefore mention only some of the different angles from which inventors have approached the proposition.

Nearly all of the earlier inventors apparently had one object clearly in mind, and that was to fire a locomotive by machinery, not particularly for the purpose of reducing the fireman's labor, but to make it possible to use a helper, or common laborer, on the fireman's side of the locomotive in lieu of the regular fireman. This is well illustrated by the fact that with nearly all of the early stokers the operator was still required to actually shovel all of the coal into the stoking machine. The stoker was to do the work of putting the coal into the firebox and distributing it, the man was to be protected somewhat from the heat of the firebox, but the labor of shovelling the coal still remained.

It will readily be seen that such inventors were building their structure upon a false basis in assuming that stokers would be applied to any large number of locomotives for the simple purpose of reducing the grade or the class of labor and entirely overlooking the long-established practice of recruiting the engineers needed for the right-hand side of the locomotive from the firemen

who have served their time and secured partially a locomotive engineer's experience through their years of service on the left-hand side of the locomotive.

Other inventors seemed to have in mind, as the main object for the use of a mechanical stoker on a locomotive, the preparation of the coal, and elaborate arrangements were made in the matter of crushing mechanism to handle lumps of coal twelve inches in diameter and over, so that the fireman would not be required to touch the coal in the coal-pit, and, having accomplished this, insufficient attention was given to the matter of putting the coal into the firebox and properly distributing it.

Several inventors brought out very elaborate devices for distributing the coal over the fire-bed, without making any arrangements whatever for the preparation of the coal or the conveying of the coal to the distributing mechanism.

Other inventors fully appreciated the arduous work of a locomotive fireman and the intense heat he is called upon to endure during the summer months under certain operating conditions, and were earnestly endeavoring to develop a locomotive stoker which would relieve the fireman from a large part of his physical labor and make it unnecessary for him to undergo the suffering due to the heat.

Some inventors confined their efforts exclusively to the proposition that the mechanical stoker would be a fuel-saving device. This was particularly true as to inventions in England and on the continent of Europe, where the cost of locomotive fuel is several times as much per ton as with us. Locomotives are being fired in Greece, for instance, with coal costing $12 per ton.

In the main, these experiments were along the conventional lines of hand-firing practice; that is to say, the delivery of the coal to the firebox in charges of fifteen to twenty pounds, as with a hand scoop, and the putting in of a "fire"; that is to say, a quantity sufficient for a period of more or less length, according to the way the locomotive was worked.

A few inventors, two in particular, whose inventions will be described later in this paper, were approaching the problem from an entirely different angle than the earlier history of the art disclosed, namely, to bring out machines which would assist the regular fireman in firing the locomotive in a better way and to a higher point of efficiency or to a greater horse-power output than was possible to do with hand firing, and at the same time do all

that other inventors had done, or even go further in the matter of relieving him from physical labor and discomfort, or exhaustion.

It is only within the past three or four years, particularly the last three years, that mechanical stokers for locomotives have been brought out which included all necessary features to successfully meet the present operating conditions on large locomotives and be worthy of application in a large way.

Considering the mechanical stokers which have been applied and are still in use on locomotives, we may properly divide them into two general classes, namely, those which feed the coal to the firebox up through the fire-bed, and are commonly referred to as underfeed stokers, and those which feed the coal to the firebox over the top of the fire-bed, and are usually referred to as overfeed, or scatter type of stoker.

The underfeed stokers are of two types: those which feed the coal through the fuel troughs underneath the fire-bed with plungers, and those which distribute the fuel in the troughs with helicoid screws.

The overfeed stokers are more miscellaneous in character: There are those which distribute the coal over the fire-bed with plungers or other mechanical means, with steam jets without other directing means, and with steam jets with stationary directing means, and also with steam jets supplemented by movable mechanical directing means; also with steam jets having constant blast and with steam jets having intermittent blast; and both the underfeed and overfeed stokers might again be subdivided into those which supply the fuel intermittently to the firebox, putting in what the firemen call a fire or "slug" and then waiting for its consumption before another operation takes place, and those stokers which supply coal to the fire constantly in proportion to the rate of combustion.

There are conveyors for both the underfeed and overfeed stokers which have reciprocating action, supplying the fuel in separate charges to the stokers and those which carry the coal constantly to the stokers. Some of these conveyors are of the pusher type, which force the coal forward by pressure, and others carry the coal through its entire travel in a free and loose state.

Where preparation of the coal is attempted, it is usually done through the means of some part of the conveying mechanism, although in the early development of the stokers separate crush-

ing machines were supplied, which, in turn, delivered the crushed coal to the conveying mechanism.

Counting all kinds of stokers which were applied to locomotives up to the year 1912, probably more than twenty-five different designs of stokers, widely variant in character, were put into service, and, strange as it may seem, *all of them fired the locomotives successfully, under certain conditions.* This peculiarity of the proposition led up to there being much misinformation circulated about the mechanical stoker for locomotives.

Some of this was also brought about by the promoters of the first stokers making unwarranted claims as to the machines being automatic, using this term even to the extent of certain companies being incorporated with the word "automatic" in their title.

This use of the word "automatic" brought immediate and very active opposition to the stoker on the part of the firemen, both individually and collectively, as they expected the "Iron Firemen" to supersede them, their wages to be reduced and their places taken by common laborers.

This fairly represents the locomotive stoker situation up to the end of the year 1911, as, notwithstanding the application of the many different kinds of stokers to locomotives in a comparatively short time, and the current reports that they were all wonderfully successful, no stokers of any consequence had been sold to the railroad companies in what could be considered a commercial way.

The American Railway Master Mechanics' Association had in the meantime appointed a Standing Committee on Mechanical Stokers for Locomotives, and several of the railroad companies also sent out committees to make investigations. The very intelligent and painstaking work of those committees contributed much to the development of stokers suitable to meet the conditions of operation obtaining on our larger locomotives of to-day, and the findings of the different stoker committees are of especial interest as an explanation of why large numbers of stokers were not applied prior to the middle of 1912, and also to forecast the characteristics of the present commercially successful locomotive stokers.

The summing up of the committees' reasons given for the non-application of stokers to locomotives in any great numbers is about as follows:

1. That most, if not all, of the locomotive stokers applied

up to the end of the year 1911 were not suited in one or more particulars to meet the variables in fuel, locomotives, and operating conditions, notwithstanding the fact that all the stokers applied up to that time actually had *bona fide* records of successful trips under certain conditions.

2. That practically all such stokers had been designed without due consideration having been given to the unusually severe requirements imposed upon strength of parts and correct mechanical design by the stress of operating conditions and the lower maintenance standards obtaining in railroad as compared with industrial service.

3. That the size of locomotives, particularly as to grate area and the tonnage hauled per train under the existing conditions of service up to the end of the year 1911, did not make mechanical stokers an absolute necessity.

4. That there was no evidence available to lead to the conclusion that a mechanical stoker would make it possible to fire a locomotive any more economically than with hand firing when the same amount of work was performed by the locomotive in each case.

5. That no advantage was being taken, to any appreciable extent, of the fact that, with mechanical stokers, large locomotives might be operated nearer to their maximum rated capacity than when hand-fired.

6. That nothing had developed up to that time to indicate that any less expensive fuel could be used for firing locomotives with a mechanical stoker than with hand-firing.

7. That it would not be possible, as claimed by some of the stoker inventors and promoters, to do away with the regular locomotive fireman and have the work done by a helper.

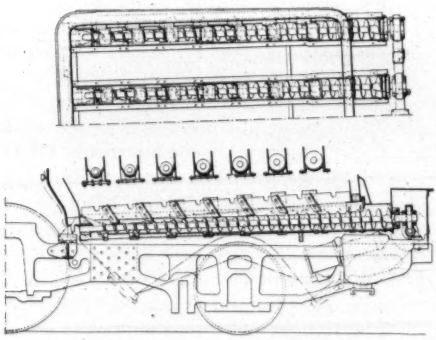
8. That labor-saving devices are not usually applied to any great extent simply to reduce the grade of or character of the labor—nor are they put into general use solely for the purpose of uplifting the grade and character of employment.

9. That therefore the only consideration left as an argument for the general application of mechanical stokers to modern locomotives was the possible reduction in the amount of physical labor and suffering of the regular fireman sufficiently to enable him to do the work without other relief.

A review of the history of the exploitation and introduction of a large number of labor-saving devices discloses the fact, re-

grettable as it may seem to have to admit it from a humanitarian standpoint, that most labor-saving devices are not applied generally unless there is some remunerative return to the purchaser, outside and apart from the ethical considerations; that is to say, there must be some increase in efficiency, some conservation of energy, some contribution to the wealth of the individual or the community at large, or the device must fail.

It is my intention to try to make it very plain that while the application of mechanical stokers to our large freight and pas-



Plan view of Barnum underfeed stoker.

senger locomotives will, in fact does, effect a very great relief to the firemen from the strenuous labor incident to shovelling coal at the rates required to fire locomotives, photographs of which will be shown upon the screen to-night, and that the firemen are almost entirely relieved from the suffering due to the heat effects of having the fire door open when hand firing, yet these benefits are only incidental to the main issues which contribute to the necessity for, or economy of, the application of stokers to locomotives.

Counting all stoking machines applied to locomotives up to April 1st of this year, there have been about 1200 put into service, of which about 1000 are now in use. This number is divided as follows:

1 Gee stoker—overfeed type.
20 Standard stokers—overfeed type.

20 Hanna stokers—overfeed type.
365 Crawford stokers—underfeed type.
600 Street stokers—overfeed type.

The 200 stokers applied at one time or another and later removed were not of these makes, with a few minor exceptions.

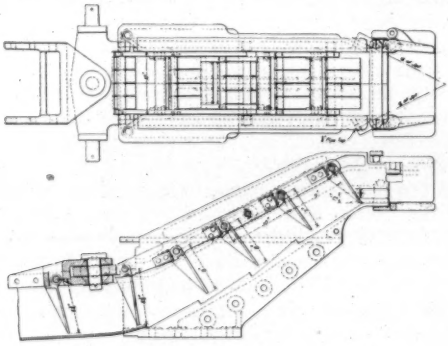
Before proceeding further with the general aspects of the subject, I should like to have you familiar with the details of these machines and some of the locomotives on which they are in use.

This is a plan view of the Barnum underfeed stoker. This was one of the stokers applied to locomotives experimentally and later on removed. One of the other slides will show the locomotive to which this stoker was applied. This stoker is of the underfeed type, having two or more stoking troughs placed longitudinally of the firebox. This drawing shows seven of the stoking troughs, but only three or four were used in the actual installations. The troughs were supplied with cast-steel helicoid screws, the flights of which were reduced in size at different points in their length, each diameter being about two feet long, and at the offset, where the reduction in flight took place, deflectors or partial partitions were provided, with an aperture equal only to the next reduced diameter of the flight of the screw. The effect of the use of these deflectors was to cause the coal to be lifted up out of the stoking troughs and forced over on to the grate areas at each side, and, of course, part of the coal was carried on through the reduced openings in the partitions until the next deflector was reached, where more coal was deducted from the quantity being forced along in troughs, and this continued until part of the coal had been carried to the extreme forward end of the firebox and forced up out of the trough by the bottom being slightly inclined upward. These stokers were operated by the use of two double-acting steam engines, one placed on each side of the locomotive at the end of the cross shaft. The screws were driven with worm drive, the worms being on the cross shaft and the worm wheels being at the back end of the cast-steel screws. Separate crushers of ample capacity were placed on the locomotive tender to prepare the coal.

Seven or eight of these stokers were applied and at least four or five of them saw considerable service with quite a number of

different kinds of fuel and on locomotives of different types, at least one each being applied to a Switch, a Prairie, a Mikado, and a Decapod type of locomotive.

The results in service were quite satisfactory when the conditions existed which were favorable to the use of this kind of a stoking machine, and many successful trips were made with these stokers, taking the average of which it could probably be said that



Plan view of Gee overfeed stoker.

75 per cent. of the coal burned on the trips made was fired by the stoker. The difficulty with this particular machine was probably more from mechanical shortcomings than from any inherent defects in the general scheme, although the results were not equally satisfactory with all kinds of coal used. It will be readily appreciated that, with the method used in firing with this stoker, there would not be the flexibility of control of the fire that will be noted with other stokers which will be shown and described.

This is a general plan view drawing showing the forward part of the conveying mechanism of the Gee overfeed scatter type of stoker and also the movable directing wings which are placed above the firing plate at the bottom part of the ordinary fire door. One of these stokers has been applied to a consolidation locomotive on the Pennsylvania Railroad, and is in operation in regular service to-day, firing the locomotive successfully. A crushing mechanism is placed at the back part of the conveyor of this

stoker, which also serves as a measuring or feeding device to start the coal into the forwarding means of the conveyor.

This view also shows a cross-section of the forwarding vanes of the conveyor. These are not made all in one piece, but are practically fingers which drop back of the coal in the backward movement of the reciprocating conveyor and serve to push part, or all, of the coal in their vicinity forward, to be engaged by the next succeeding set of fingers in the following action of the conveyor. The reciprocating action of this type of conveyor accomplishes the purpose not only of forwarding the coal but of partially measuring it and serving it to the firing plate in separate charges, and the steam blasts are operated in timed relation to the forwarding of these separate charges of fuel, and serve as plungers to inject the coal into the firebox in very much the same manner as it would be fired with a scoop.

The direction of these separate charges of fuel to the different parts of the firebox is accomplished by the movement of the wings, in relation to which the jets are also controlled, so that when the wings are pointed toward the left-hand side of the firebox the jet on that side is shut off and the right-hand jet serves to force the charge of fuel in conjunction with the wings over to the left-hand side of the firebox, and so on.

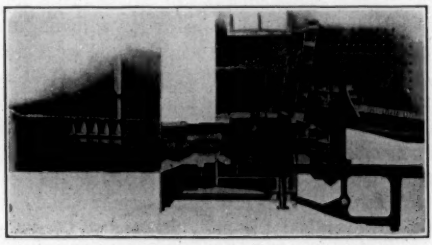
Photograph of general view of Gee stoker applied to locomotive and tender.

This is a photograph showing the general view of this stoker and with the deck of the tender and locomotive removed, so that the conveyor can be seen almost through its length. The crushing mechanism is just back of that part of the conveyor shown in the lower margin of the photograph. The position of the stoking mechanism itself, just below the fire door, can be readily observed in this view.

This stoker is operated by means of a steam cylinder placed at the side of the locomotive and attached to the frame just below the fireman's seat-box. The connection between this operating steam cylinder and stoker is by means of a cross shaft with the necessary arms and connections to give the conveyor and elevating mechanism the reciprocating action required by this particular design of forwarding means.

The individual characteristics of this particular stoker are *the firing of the coal over the fuel bed in separate charges*, representing very nearly the general scheme of hand firing and *the necessary intermittent action needed to permit each charge of fuel to be consumed before another is placed in the same location in the firebox*.

This stoker is firing a locomotive successfully, but has not been in service long enough to warrant any conclusions as to its commercial possibilities, only one of them having been put into service to date.



General view of Standard stoker.

This is a general view of the Standard stoker showing arrangement of conveyor, jets, and grates. This stoker is also of the overfeed scatter type, but it has the peculiarity of firing the locomotive by putting the coal into the firebox by conveying it to

a point just below the back section of the grate area and elevating it by a vertical screw placed in a firing pot in the middle of the back part of the firebox. The distribution of the coal over the grate area is by steam jets, the nozzles for which are placed so as to come in the midst of the body of coal just as it reaches the top of the vertical screw, and the distribution is secured by having the jets pointed toward different parts of the grate area. There are no movable or stationary mechanical directing means to assist the steam jets in distributing the coal as with other stokers.

This stoker is one of those designed to supply fuel at a continuous rate over the entire grate area as compared with the intermittent action of the Gee stoker, which fires the coal in separate charges, as just described.

The Standard stoker also has arrangements for crushing or preparing the coal, this being accomplished by the use of a crushing zone at the forward end of the heavy cast-steel helicoid screw shown in the left-hand section of this general view. The necessary flexibility for the movement between locomotive and tender is secured by the ball joint actions, also plainly shown in the view.

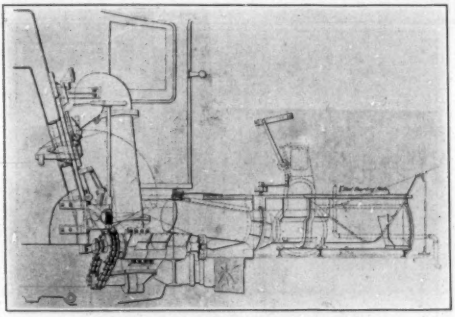
The power motor which operates this stoker is a small, high-speed steam turbine on the left-hand side of the locomotive, and connection is made to the stoker through a train of gears with suitable reversing mechanism required for the clearing of the stoker from foreign matter or clogs of any description.

Suitable arrangements are provided for adjusting the jets to different degrees of force and also to shut one or more of them off when it is desired to stop the forcing of coal to any given part of the firebox. The general action of the jets is intermittent, being controlled by an operating valve moved mechanically by the arm and rod connection shown.

It might occur to you that the action of the jets being intermittent would result in firing separate charges of fuel to the grate area. This, however, is not actually the case, as the action of the jets is graduated so that the building up of the blast to maximum and decreasing in force to the minimum serves the purpose of waving the coal over the grate area by the use of the increasing and diminishing forces of the jets, and the valve controlling the jets begins to open almost immediately after each jet action, so

that the result is a spreading of the coal continuously rather than firing it in separate charges.

Some fifteen or sixteen of these stokers have been applied to locomotives to date, and are firing the locomotives successfully.

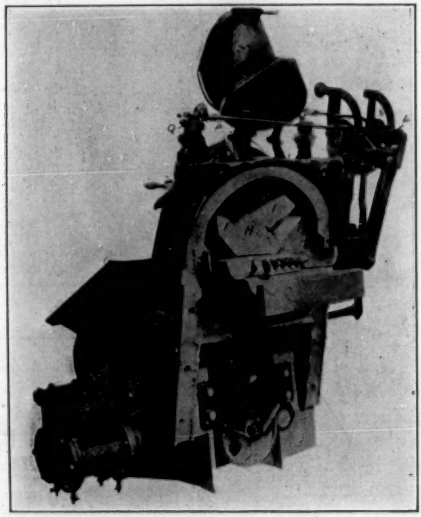


Drawing showing arrangement of Hanna stoker.

This is a drawing showing the general arrangement of the Hanna overfeed scatter type locomotive stoker. The peculiar characteristic of this stoker is the use of a combination of *movable mechanical directing means and continuously operating steam jets* for distributing the coal over the grate area. It also has means for crushing the coal preparatory to forwarding it to the elevating and firing means.

The driving motor is a twin-cylinder, double-acting steam engine placed on the locomotive tender, usually in one of the forward ends of the water space. The operating routine is to have the coal passed to the crusher through the opening in the deck of tender, and after being crushed the coal is forwarded by a cast-steel helicoid screw to a receptacle at the base of the elevating means, which is another cast-steel screw placed in the vertical casing just at the left of the ordinary fire door of a locomotive. At the top of the elevating means is a large elbow, or goose-neck, through which the coal is forced by the pressure of the vertical elevating screw and finally falls by gravity over the directing vanes, or wings, to the firing plate placed inside of the regular firing door of the locomotive.

This photographic view shows the firing plate, above which will be noted the main nozzles of the firing jets placed in fan-shaped arrangement, and above these jets will be seen the ridge plate and movable mechanical means or directing wings, which serve to assist the jets in distributing the coal over the grate area.



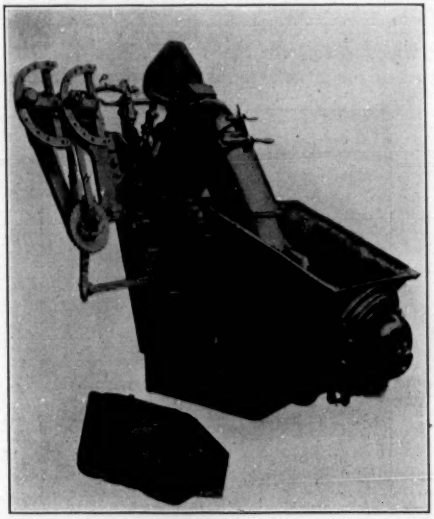
Photograph showing views of firing plate, steam jet nozzles, and stoking mechanism of the Hanna stoker.

Just below the main jets is a long slot in the casting at the level of the firing plate, and this can just be seen in the view.

The operation of the mechanism shown in this view is about as follows: The coal reaches the vanes at the upper part of the opening, coming by gravity from the goose-neck, and these vanes are in turn operated by the levers placed on backhead of locomotive, which will be shown in the next view, these levers keeping the vanes in constant motion while the stoker is in operation, which results in the coal being poured down over the jets, and the stream of coal is gradually directed from side to side, so that

the jets pointed in any given direction intermittently force part of the coal, as it is directed over them, to some portion of the grate area; these jets being arranged in the segment of a circle, and the passing of the coal gradually from side to side in front of them has the effect of waving the coal over the grate area from one side of the firebox to the other. Steam also is forced against the coal through the long slot just below the main jets, but at a lower pressure, and this serves to force part of the coal just over the firing plate to the back of the grate area.

This delivery of the coal to one side of the firebox for a short time and the similar delivery in turn to the other side would make it proper to classify this stoker with those of the intermittent firing type, as a charge or "fire" is, in a partial sense at least, delivered to the different sides of the firebox and allowed to burn until the cycle of mechanical movement brings another delivery of fuel. The jets are constantly in action, the mechanical direct-

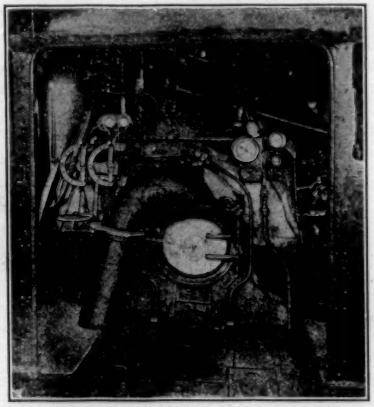


Photograph showing the adjustment levers for control of distributing wings of Hanna stoker

ing means are also continually in motion; but the delivery of the fuel is intermittent—an arrangement just opposite from that of most stokers of the overfeed type.

The fan-shaped arrangement of main jets serves also as a fork, or set of fingers, to partially separate the coarser lumps of coal from the fine slack, which latter drops to the firing plate and is forced to the grate area by the low-pressure steam emitted from the long slot just mentioned; the larger particles are more violently forced by the steam jets to other parts of the grate area.

This is a photograph of one of the earlier forms of the Hanna stoker, but will serve in this connection to show the arrangement of control levers which operate the movable mechanical means which assist the steam jets in distributing the coal as just described, this lever arrangement being the same in the present installations of this stoker as shown in this view. The hopper shown was the receptacle into which the coal was shovelled manually. The moving of the small levers on the quadrants here shown has the effect of changing the range of movement of the directing wings so that the coal may be kept directed toward a limited part of the grate area, or by moving these levers on the

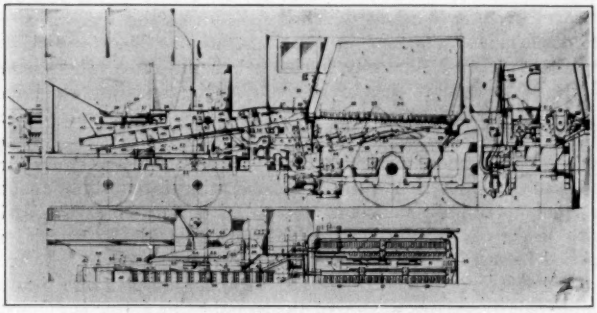


Photograph of backhead of locomotive showing Hanna stoker device lowered for hand firing.

quadrants the range may be changed so that the movement is over the entire grate area.

It will readily be appreciated that as this stoker is applied to the ordinary fire door of a locomotive it is essential that some means should be furnished for getting the stoking mechanism out of the way in the event of failure, or for the purpose of building the fire at the round-house by hand, and this view shows the upper part of the elevating means and the goose-neck, but the main stoking mechanism has been lowered below the deck of the locomotive cab. At the left of the goose-neck will also be seen the quadrants and operating levers shown in the other view.

Approximately forty of these stokers have been applied to locomotives to date, about twenty of which of the latest design are in daily service and firing locomotives successfully. About twenty of the earlier forms of this stoker, with which the fireman was required to shovel the coal into the hopper below the elevating means of the stoker proper, were applied to locomotives, but found to be either not practical or of sufficient advantage to warrant their continued use. Those at present in service, however, are giving good satisfaction.



Drawing showing general arrangement of Crawford underfeed stoker.

This is a drawing showing the general arrangement of the Crawford mechanical underfeed stoker as in use on a large number of Consolidation and Pacific type locomotives on the Pennsylvania Lines West.

This stoker was designed and developed by Mr. D. F. Crawford, General Superintendent Motive Power, Pennsylvania Lines West, and, as it was one of the first stokers to be applied to locomotives other than in an experimental way, it is of special interest in connection with the subject of the evening.

As explained earlier in this paper, the different stokers which have been developed have each individual characteristics as to mechanical design and method of handling the fire. This stoker is the foremost representative of the underfeed principle of firing; it has been in continual operation for the past four or five years, and well illustrates what can be done in the matter of successfully firing locomotives in that way.

The Crawford stoker is designed on the theory that the use, more or less completely, of the coking or gas producer process, during the progress of combustion, contributes toward economy and reduces the amount of black smoke usually made by a locomotive when working at or near its maximum output, and to secure this coking of the coal the fuel must be supplied to the fire from the bottom upwardly, hence the term underfeed stoker.

The mechanical arrangements of this stoker include preparatory means, or crusher, at or near the back part of the reciprocating forwarding means, which are shown on the forward part of the locomotive tender in this illustration. The forwarding means are placed generally horizontal, being only raised sufficiently at the front to elevate the coal over the top of the receiving hopper, in the bottom of which the main feed plungers operate. The crushing mechanism also serves the purpose of a measuring and feeding device to prevent the overloading of the conveyor. It is timed in operation with the reciprocating forwarding means, and only permits a sufficient amount of coal to enter the back part of the conveyor as can be readily and without congestion carried forward in the normal operation thereof.

The conveyor is made up of sets of fingers carried on a frame and hung from above the top of the trough; this frame is reciprocated forward and backward with considerable travel, so that the vanes or fingers, the bottom ends of which just clear the bottom of trough, serve to carry the coal forward and in the return stroke are lifted over the top of the coal which has just been moved toward the front end of the conveyor trough, and some of them

in each set drop behind the coal below them, and in turn carry some more coal forward.

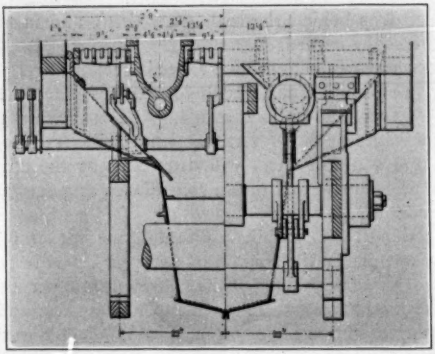
The purpose of making these vanes in sets of fingers is to prevent a lump of coal keeping the whole vane raised up, which would then move forward without carrying the coal with it, but by cutting the vanes up into several sections, or fingers it is found in practice that some of them will drop back of the coal in that section of the trough, and thus a general carrying forward of the coal is secured.

The action of the crushing, or feeding mechanism placed just below the opening in the coal pit of tender is timed in relation to the reciprocating movement of the conveyor, and is connected by substantial mechanical means to the operating steam cylinder on the locomotive, so that its action is powerful enough to crush any large lumps of coal which may drop into the crushing area in front of the piston and be broken up in the operation of being pushed through the feed opening into the back part of the conveyor, the lumps then being small enough to be readily taken up by the vanes or sets of fingers in the conveyor, as shown in this drawing, and forwarded, as just described.

The coal, on reaching the forward end of the conveyor, drops into a hopper in the bottom of which are the main feed plungers, which operate in a substantial casting placed just under the backhead of locomotive boiler.

In the firebox are placed two heavy cast-steel fuel troughs, into the back part of which the feed plungers force the coal. At points spaced throughout the bottom of the fuel troughs are auxiliary plungers which serve to assist in forwarding the coal still farther forward. Small castings in the shape of fingers or teeth are placed adjacent to the outward end of the auxiliary pistons to assist in enlarging the end thereof, and serve as agitators to keep the coal moving forward in the feed troughs as the auxiliary plungers are operated.

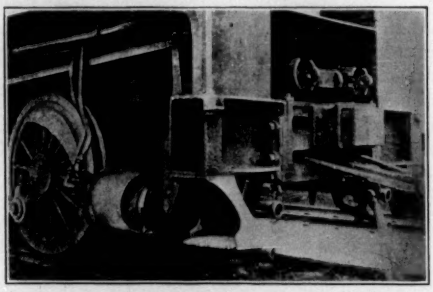
The grates of the firebox, of special form, are placed between the troughs and also between the extreme right and left troughs and the sides of firebox, and may be either level or at an angle of something like 42 degrees to represent the normal angle of the coal at rest as it is forced over the sides of the troughs by the feed and auxiliary plungers.



Section showing shape and size of main feed trough of the Crawford stoker.

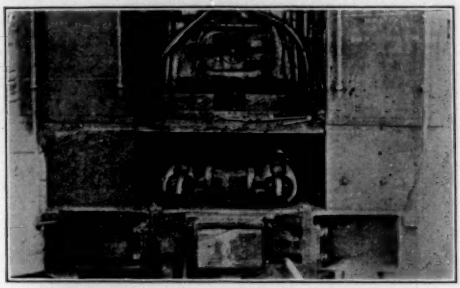
This view will show the troughs more in detail and the grates at each side. In this drawing the grates are of the level form.

The Crawford stoker is operated by means of a steam cylinder attached to back end of locomotive frame on left side of locomotive, and is connected to the stoker mechanism through means of cross shaft with arms thereon to attach to the steam cylinder, the conveyor, the crushing mechanism, and the main and auxiliary feed plungers.



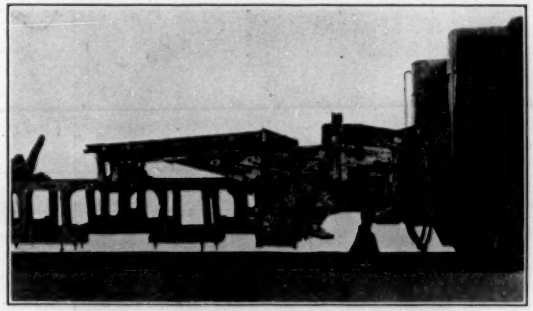
Photograph showing operating cylinder of Crawford stoker attached to locomotive frame.

This photograph shows the main operating cylinder of the Crawford stoker and the back part of main feed plungers.



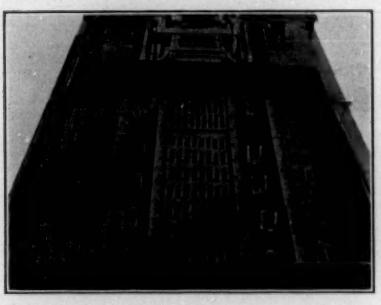
Photograph showing main feed plungers, Crawford stoker.

This photograph shows the back part of main feed plungers of the Crawford stoker and, rather indistinctly, the upper part of coal hopper in which the plungers operate.



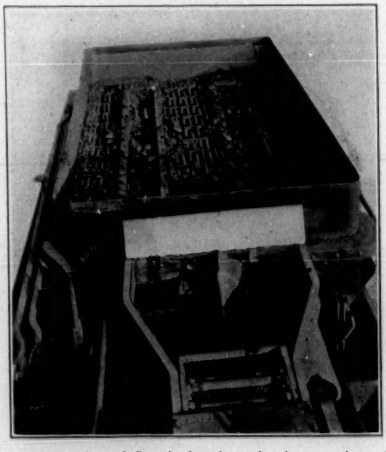
Photograph of general arrangement of Crawford stoking mechanism.

This photograph, while not very clear in its details, will serve to show the general arrangement of the stoking mechanism of the Crawford stoker and the forward end of the conveyor just above the feed hopper. The operating cylinder and lever attachment to cross shaft can also readily be observed.



Photograph of general plan of Crawford stoker, showing trough and grate arrangement.

These photographs will perhaps serve to give a better idea of the general arrangement, grates and stoking troughs of the Crawford stoker.



Photograph of general plan view of Crawford stoker, showing troughs, agitators, and main feed hopper.

The agitators on auxiliary plungers can be seen in this view and also the main feed hopper and feed piston positions.

The method of firing is about as follows:

The reciprocating action of the crushing and conveying means brings the coal to the main feed hopper, and it is directed toward each feed piston by a ridge plate therein. Each main feed piston forces its portion of these charges into the back part of the main feed troughs in the firebox through openings in the casting underneath the mud ring.

In this operation any lumps of coal which are larger than these openings will, of course, be additionally broken up by a similar action to that of the main crushing and measuring piston. These charges of fuel, forced into the trough in this way, serve as forcing means to push the coal, already in the troughs, still farther along, where it is taken up by the auxiliary feed pistons, and at the same time some of it is forced over the sides of the troughs as it travels toward the forward part of the firebox. The troughs are usually made with slight offsets in their widths which serve as abutments or partitions, similar to those described in the Barnum stoker, and these partially assist in lifting the coal up out of the troughs to the grate area. The forward end bottoms of the troughs are inclined upward, so that the small amount of coal which reaches the vicinity of the throat sheet is in turn lifted out of the trough on to the grate area in the front part of the firebox.

In firing a locomotive with this stoker, the fire is initially made in the round-house by hand firing in the ordinary manner. The stoker is usually not put into operation at all until the locomotive begins to do actual work in hauling the train.

The coking process is secured in the operation of this stoker by the filling of the feed troughs and supplying of sufficient coal to the grate area at each side thereof to make it possible for the fire to be maintained at a proper point without the stoker being operated continually.

The stoker is operated possibly ten strokes or so at a time; that is to say, a " fire " is put in and allowed to be undisturbed for a suitable period to permit the coking to occur.

During the time the fire is undisturbed by the operation of the main and auxiliary feed pistons of the stoker the green coal on the top of the feed troughs becomes ignited from the heat of the fire on the grates, and the fire is then well ignited over the entire firebox area. A casual observation of the fire at this time would

not disclose the feed troughs at all. As no air is admitted up to the fire through these feed troughs, the ignited coal, on top of the troughs, together with the general heat of the firebox, serves to distil and break up the volatile matter, the hydrocarbons, from the next lower stratum of coal in the troughs. If the operation of the stoker is timed properly this stratum of coal becomes coke, and the next operation of the main feed and auxiliary plungers serves to force more green coal along the troughs, which in turn lifts the coked coal and turns it over on to the grate area.

Without going into the theory of combustion, it might be well to state that this gas-producing effect of the coking process undoubtedly contributes toward economy by breaking up these hydrocarbon contents very early in their travel as they pass through the ignited stratum as explained; the hydrogen combining with oxygen earlier than it might otherwise have done, and the carbon, requiring more time or raising to proper temperature, also starts to combine with oxygen nearer the fire-bed than with hand firing.

It will readily be observed that in order to secure this coking process there must be a proper time element introduced at intervals in the operation of the stoking mechanism, and the regularity of these intervals and the length of time the fire is at rest has much to do with the perfection of operation when firing a locomotive, or stationary boiler, for that matter, in this manner. If the demand upon the locomotive is such that the stoker pistons must be kept moving rapidly to supply a sufficient amount of coal to keep the engine hot, then, of course, the coking process is disturbed, more smoke is made, and probably less economy secured.

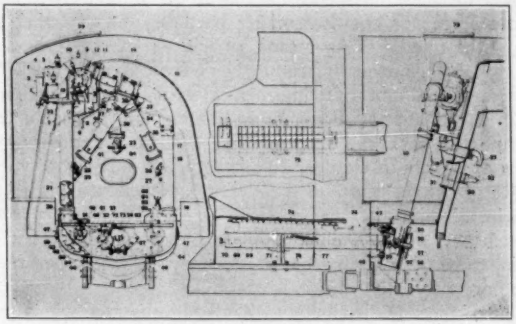
Any one who has observed the operation of firing a locomotive with this stoker in actual service will admit at once that this is a very excellent way of accomplishing the desired result, and it is no wonder, therefore, that this method has its earnest adherents.

There are nearly four hundred of these stokers in actual service, certain divisions of Pennsylvania Lines West being completely equipped, and they have been in service for the past three or four years with such success that this stoker may be considered very properly as one of the possibilities for general application.

Having thus described the underfeed stoker which has so successfully demonstrated the correctness of the theory of that method of firing a locomotive, you will no doubt be interested in the next description, which is that of the Street locomotive stoker,

of which some six hundred are now in service on very large modern locomotives. It may very properly be considered as the principal representative of another method of firing; namely, that of supplying coal to the entire surface of the fire continuously at *the rate of combustion,* no coking periods being provided for as in the method just described.

The modern locomotive is called upon to operate at widely varying rates of horse-power output, often from maximum to zero within very short spaces of time, and this method of firing is based on the theory that there should be a given rate of combustion per square foot of grate area at any given time just sufficient to supply the steam output required of the locomotive boiler at that time; that is to say, there should be the same flexible control of the fire that there is of the throttle and cut-off.



Drawing showing general plan of Street locomotive stoker.

This drawing will give you an idea of the general arrangement of the Street locomotive stoker, which consists of a conveying, elevating, and stoking mechanism.

This stoker is designed to handle only coal which will pass through a screen having openings not to exceed three inches square. A screen of this character is placed just below the bottom of coal pit of locomotive tender, and above this screen are placed movable slides, so that a portion only of the screen is exposed at one time. Below the screen is placed a conveyor trough in which is operated the forwarding screw of helicoid form, which serves to carry the coal forward to the receiving

hopper which constitutes the bottom part of the elevating mechanism.

In the left-hand section of the drawing is shown the general elevating and driving mechanism of the stoker. The endless chain of elevator buckets is driven by a single-acting, high-speed engine built into the upper left-hand part of the elevator, as will be plainly noted on the drawing. This high-speed engine drives the endless conveyor through means of worm, worm wheel, and the usual arrangements of sprocket wheels placed at different points. No sprocket is placed at the upper right-hand section of the elevator casing, however, as it is necessary to drop this part of the casing to clear the locomotive throttle connections which are at this point on backhead of locomotive.

In the centre of upper section of elevator casing is placed the mechanism which apportions the coal to the different firing points by first screening out the smaller particles and directing them toward the middle firing means, as will be later described, and then equally, or unequally, as may be desired, dividing the coarser particles of coal and directing them toward the side distributers.

On the right-hand side of the drawing will be seen a cross-section of the backhead of locomotive giving a better view of the hopper at bottom of elevator and showing the downwardly directive feature of the centre distributer; the purpose of this being to assist in directing the finer particles of coal or dust to a zone in the back part of the firebox, where these small particles will be less apt to be taken up by the draft and carried away before they can be properly consumed.

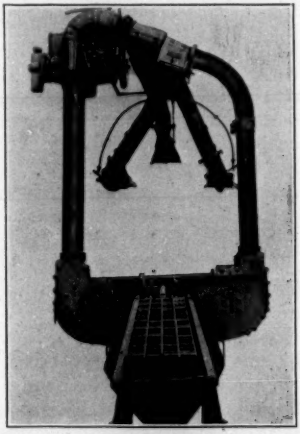
One of the side distributers will also be observed which serves to direct the coal generally forward, and on the bottom of which are placed directing ribs which assist in spreading the coal over a fan-shaped zone on each side of firebox. Each of the side distributers directing the coal over a fan-shaped zone in this way serves to cover the main part of the grate area, overlapping slightly in the centre of the firebox, leaving a small, triangular area at back of grate, which is covered by the finer coal directed there by the centre distributer as just mentioned.

The distributers at the side and centre are simply rough castings removable from the ends of the tubes which are placed in openings through backhead of locomotive boiler, and which permit their replacement when warped or destroyed by heat of firebox after their normal period of service.

At the point of connection between the delivery tubes and the distributers are placed elbows, and through the backhead are the removable tubes to which the distributers are attached on inside of firebox. In the elbows are placed firing nozzles, to which are made steam connections from the blast device, the latter operated by the stoker motor.

Photograph showing directive rib on stationary distributers—Street stoker.

This photograph will give you a better idea of the directive ribs placed upon the lower part of the centre and side distributers for the purpose of assisting the blast device in distributing coal over the grate area to the different zones described.

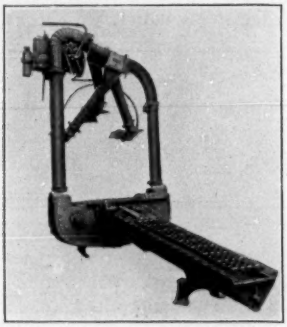


Photograph of end view of assembled Street locomotive stoker.

This photograph of end view of Street stoker, assembled for exhibition purposes, will give you a better idea of the general

arrangement, the view being directly toward the backhead of boiler.

This view will assist in showing the relation of the parts, especially the coal screen above the conveyor trough and the slid-

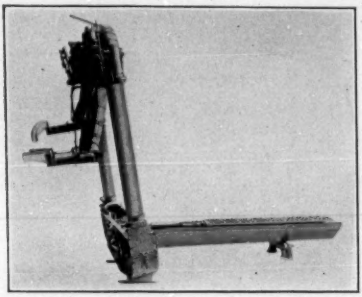


Photograph of quartering view of Street locomotive stoker.

able connection of the conveyor trough on the tender. The whole stoker being attached to the locomotive proper, the necessary flexibility between locomotive and tender is provided for by swivel connection at forward end of the conveyor trough at the point where it is attached to the elevator hopper, and the fore-and-aft movement incident to the usually loose coupling connection between locomotive and tender is provided for by simply having the conveyor trough slide upon the bracket placed below the trough, as can be readily observed in this photograph.

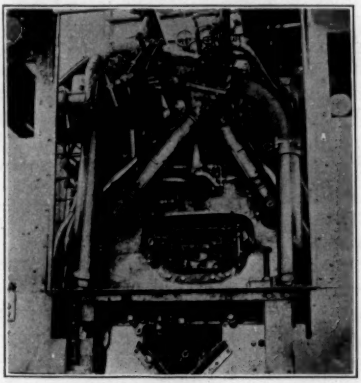
This photograph of the general side view of the stoker will give you a better idea of the driving means for operating the conveyor screw through sprocket connections on back of hopper, which are in turn operated by the endless elevator chain of buckets as they pass the main sprocket in lower left-hand part of elevator hopper, and also the elbows, tubes, and distributers which are placed on and through the backhead of the locomotive.

This view, showing the actual installation on a Mikado locomotive, will serve to show the general arrangements of an installation, and particularly the ordinary fire door, which is left available for such observation of the fire as is necessary, or hand firing to build the fire initially in the round-house and care for



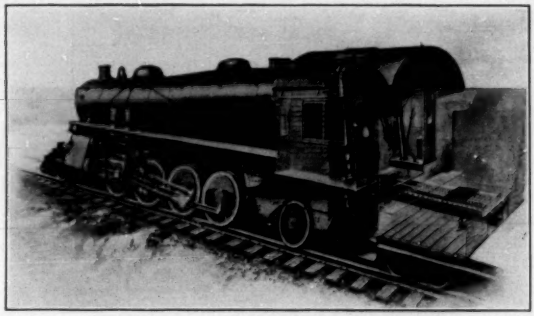
Photograph of general side view of Street locomotive stoker.

the fire when the locomotive is standing by at terminals or on sidings.



Photograph of view into locomotive cab of Mikado locomotive equipped with Street stoker.

This is a photograph of a pen-and-ink sketch of a large Mikado locomotive equipped with the Street stoker, and will serve to give a better conception of the general arrangement of the openings above coal screen and the availability of the ordinary fire door and the usual space in cab for locomotive engineer and fireman. This view also shows a sliding door provided in roof of cab for inspection of stoker motor.



Photograph of phantom view of Street locomotive stoker.

As I mentioned earlier in the paper, this stoker is particularly representative of that method of firing by which the coal is put into the firebox above the level of the fuel bed and dropped upon the surface of the fire continually, while the locomotive is being operated, and distributed over the entire grate area at the rate of combustion. Other stokers have been designed to partially carry out this method—the Hanna stoker, for instance, while putting coal into the firebox continually, does not spread it over the entire grate area at the rate of combustion, as it will have been observed that the movable mechanical directive means which assist the jets in the Hanna stoker in distributing the coal have the effect of putting coal to the different parts of the firebox in excess of the rate of combustion and then moving the directed stream of coal toward other parts of the firebox to permit the coal, just delivered, to be consumed in the meantime.

The routine of the process of firing a locomotive with the Street stoker is about as follows: The coal is assisted in passing down through the slide opening just in front of the main body of coal in the locomotive tender by the movement of the tender screen, this screen, by the way, being operated through a travel of three or four inches fore and aft by mechanical means and connections in the main elevator hopper. This movement of the screen materially assists a stream of coal being regularly delivered to the conveyor trough just below the opening, where it is carried forward and dropped into the main elevator hopper.

The endless chain of buckets, each bucket lifting about one

pound of coal, then takes up the coal and carries it to the main discharge pipe in upper section of elevator casing, where it is again screened, divided, and directed toward the firing elbows. The coal drops by gravity to these elbows and is forced into the firebox by steam jets which are controlled by the blast-controlling device operated by main driving shaft of the elevating mechanism. The cams on this blast device are within the control of the fireman, so that the interval and duration of the jets may be adjusted to meet the conditions of operation. The jets are intermittent in action, but the coal is admitted to the firebox continually and is, in effect, scattered over the entire grate area all of the time while the stoker is in operation.

During the slight interval between the operation of the jets the coal is carried into the firebox from the firing elbows by the draft of air which enters the firebox at the stoker openings and is carried partially over the grate area, and, as the jets start, the coal is still further driven forward and, as the pressure of the jet increases, the wave of coal is projected farther and farther toward the throat sheet. As the pressure begins to die down the main wave of coal is then spread, with less force, toward the back part of the grate area.

The distributers, or stationary mechanical directing means, are placed above, rather than below, the tube openings just inside of the firebox, and on the bottom part of these distributers are the directing ribs which you have seen. The main purpose in placing these distributers above the openings is to direct the coal downwardly rather than forward. The steam jets, acting as plungers, force the coal forward, but at the same time the expansion of the steam as it leaves the nozzles would lift the smaller particles of coal to the upper part of the firebox and some of it might be carried on over the arch and through the tubes without being consumed. The distributers serve the double purpose, therefore, of keeping the coal downwardly directed toward the grate area and at the same time materially assist in spreading it.

The motor which operates the stoker has a variable speed governor—variable speed in the sense that it can be set to run at different rates of speed as may be required to drive the conveying, elevating, and stoking mechanisms at speeds suitable for supplying coal in proportion to the amount required for any given output of the locomotive.

The several constant speeds of the stoker motor make it pos-

sible for the fireman to set the stoker to run at the different rates for any interval of time that the locomotive may be operated with any particular setting of the reverse lever and throttle. The highest speed of the stoker motor represents the delivery of the proper amount of coal to fire the locomotive to its maximum capacity, and at the lower speeds at which the motor can be set the delivery of the coal will be in amounts proportioned properly to operate the locomotive at several different rates of output. The relation between the delivery of the coal by the conveyor and its elevation by the buckets of the elevator is arranged for in the initial application of the stoker to any particular locomotive.

If a delivery of coal is required of less quantity than the delivery at the slowest speed of the motor, the amount can be further reduced by partly closing, with the sliding plate, the opening over the tender screen or by disconnecting the stoker motor from the stoking mechanism through means of the friction clutch which is introduced between the motor and the stoker for the purpose of readily stopping and starting the stoker when desired.

Means are also provided to permit the fireman to control the supply of coal delivered to each of the three elbows. The increase and decrease of the supply to the centre elbow are adjusted by turning larger or smaller screen openings to register with the discharge opening for the middle distributer, so that in this way more or less of the fine coal is taken out of the main stream of coal as it passes over the upper screen.

The supply to each of the side elbows is regulated by a dividing rib which can be placed at different points in the opening so that the flowing stream of coal will be divided up in different proportions between the tubes going to the side elbows.

While there are means supplied, as described, for making different adjustments of regulation of the speed, as well as the dividing means for supplying the coal to the different zones in the firebox, the adjustable features generally of this stoker are designed with the idea of permitting a definite setting to be determined, and then permitting the stoker to operate at that setting of speed or coal delivery, so that, so long as the locomotive is worked at the point requiring that particular amount or distribution of the coal, the stoker will need no additional attention on the part of the fireman other than to see that the coal is being fed properly to the opening above the screen in the tender.

In designing the Street stoker the firing problem of itself was

considered as of first importance; that is to say, the keeping of the fire in direct relation to all of the conditions of operation of a modern locomotive, especially that of securing the absolute maximum output and satisfactorily caring for the abrupt changes required of the power plant, yet it can be said that the general scheme of firing is in line with the best recommended practice and must contribute toward economy, although in a different manner from that of the underfeed method, and at the same time make it possible to burn fuel that could not be used for hand firing.

I beg leave to quote in this connection a few paragraphs from Technical Paper No. 80, issued by the Department of the Interior, Bureau of Mines, which particularly commends this method of firing, especially as to its possibilities for successfully burning slack coal:

"Soft or bituminous coal should be fired in small quantities at short intervals, the quantity that should be fired varying with the size of the grate and the intensity of the draft.

"Small and frequent firing makes the coal supply more nearly proportional to the air supply, which in most hand-fired furnaces is nearly constant. They also reduce the formation of crust on the fires and the chance of holes in the fuel bed. With small and frequent firings better combustion is obtained.

"When a fresh charge of bituminous coal is spread over an incandescent fuel bed, the coal is heated rapidly and twenty to forty per cent. of the combustible matter is distilled off in the form of gases and tar vapors. This distilled combustible matter requires for its combustion additional air. It can be readily understood that the heavier the charges, the larger amount of volatile combustible driven off two to five minutes after firing.

"To burn the volatile combustible, about fifteen times its weight of air needs to be supplied. Therefore, immediately after firing, a large quantity of air should be admitted over the fire, and this quantity should be gradually reduced as the distillation of the volatile combustible nears completion. The larger the quantity of fresh coal fired at a time, the larger the volume of air needed for the complete combustion of the volatile matter.

"*An ideal case is the one in which the coal is fed into the furnace constantly and at a uniform rate, as is done with some mechanical stokers.* The coal supply is then as uniform as the air supply.

"Small and frequent firings reduce the tendency of many

coals to fuse and form a hard crust at the surface of the fuel bed. Most of the soft coals used for steaming purposes fuse in this way, and the crust in places prevents the free passage of air through the fuel bed. In these places the fuel burns slowly. At other places in the fuel bed where the crust has not formed or where it is cracked, a large quantity of air flows through and the coal burns quickly. On account of this uneven flow of air through the fuel bed the coal burns unevenly, and as a result the rate of combustion and the capacity of the boiler may be decidedly reduced. Such fusion of coal is particularly troublesome in case the coal contains a large percentage of slack and where large quantities of it are fired at a time, for then the crust must be broken and the fuel bed levelled frequently. In an extreme case this crust must be broken and levelling done after each firing. If, however, a little coal is thrown each time on the hot fuel bed, the thin layer of fresh coal burns through before a hard, tight crust can form. Often a coal gives trouble from the formation of crust when fired in large quantities and yet burns comparatively freely (without fusing into crust) when fired in small quantities, so that a good fire can be run two or three hours without the use of a rake. Therefore, to avoid or to reduce the formation of hard crust at the top of the fuel bed, the fresh coal should be fired in small quantities so that it will make a thin layer that will not fuse and interfere with the flow of air. If the flow of air is not hindered, the layer of fresh coal will burn through without fusing into crust. As this thin layer of fresh coal burns through in a short time, the small firings must be made at short intervals.

"With frequent firings there is much less danger of holes forming in the fuel bed. The thin spots are seen and covered with fresh coal before the holes actually form. In this way frequent firing reduces the losses from excess of air."

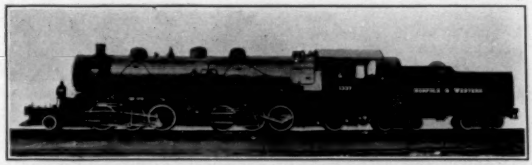
Slack was never used extensively for locomotive fuel until the advent of the Street stoker, and now something over 600 locomotives are being fired with coal that will pass through a screen having two-and-a-half or three-inch round holes.

If, by chance, a hand-fired locomotive should get a tank of this kind of fuel, the fireman would usually complain of "bad coal."

With the main points of the stoker story in our minds, as

related thus far,—that is, the aims of the different inventors in the early state of the art, the findings of the stoker committees to the effect that not much of real value had been accomplished up to the end of the year 1911, and the descriptions given of the machines sold commercially since that time and now in service,—some information about the principal stoker-fired locomotives will be the best way of illustrating the progress made in the last three years.

In connection with the description of the locomotives, I shall also try to give information about the work the stokers are doing which will enable you to judge of their present economic value and draw conclusions as to the possibilities for the future.



Photograph of Norfolk and Western Z-1 Mallet road locomotive.

This is a photograph of a Norfolk and Western Z-1 and Z-1-A road Mallet locomotive having 72,800 pounds tractive effort and 62.2 square feet grate area. Not a remarkably large locomotive, but well within what we have come to term the stoker class. There are 120 of them in service, all stoker-fired, and, from the stoker point of view, these locomotives are of somewhat unusual interest. They were practically the first locomotives to be bought new with mechanical stokers in the original specifications and the first ones to be commercially equipped. Forty of them were ordered to be furnished by the builders, complete with stokers, during the summer of 1912; forty during the summer of 1913, and forty during 1914. Of the 120, 105 have the Street stoker and 15 the Hanna.

Each of these locomotives hauls from one and one-half times to twice the tonnage of the consolidation locomotives displaced by them.

The fuel used is mine screenings or slack secured from the

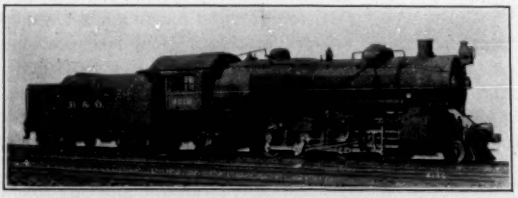
mines direct or screened by the railroad company from the coal used for hand-firing. Practically none of it could be used for hand-firing.

This locomotive was also built to be stoker-fired, is much larger than the one just shown, and, if size alone has anything to do with the need for mechanical stokers, this would be a shining example. The tractive power is 105,000 pounds and grate area 99.9 square feet. Thirty of this class are in pusher service on the Baltimore and Ohio, all having Street stokers.

Photograph of Baltimore and Ohio Mallet pusher.

The fuel used is mine screenings secured by passing run-of-mine coal over bar screens with bars placed one and five-eighths inches apart. Some of the thirty have been in service three years and all of them over eighteen months.

Using 100 pounds of coal per square foot of grate area per hour as a conservative figure for the amount of good quality coal required to fire these locomotives to their rated capacity, it will be admitted at once that this, then, would be a place for stokers, even if there were no other considerations.



Photograph of Baltimore and Ohio Mikado.

This locomotive represents another phase of the stoker proposition. The locomotives just shown are unquestionably of the

stoker class from their size alone, requiring more coal to fire them to their maximum capacity than could be put in manually, especially for any extended period. This locomotive has but 54,000 pounds tractive effort and 70 square feet of grate area, and can be fired by hand very satisfactorily in regular service. There are 320 of these locomotives on the Baltimore and Ohio, 160 of them stoker-fired with the Street stoker, 160 hand-fired. There are both saturated and superheated engines stoker- and hand-fired, so that ready comparisons can be made of the advantages, if any, of the use of the stoker on an engine of this size under various conditions of operation. Fifty of the stokers were applied during the summer of 1912, and the other 110 during the year 1913, so that all of the stokers have been in service long enough to permit these comparisons. There are two things which have been accomplished on the 160 stoker-fired engines which are of interest.

First, each locomotive stoker-fired is given more tonnage per train as its rating than the same engine hand-fired, and this increase in tonnage can be safely stated to be 500 tons for a superheated stoker-fired engine over a superheated hand-fired, and at least the same amount for a saturated stoker-fired over a saturated hand-fired, and this work is done on a stoker-fired locomotive with fuel that could not successfully be used for hand-firing in regular service. This fuel is secured by screening run-of-mine coal over bar screens with the bars one and five-eighths inches apart, or is purchased direct from the mines, this latter being the case when gas coal mine screenings are used.

A careful record kept for a considerable period of the hand-firing done on stoker-fired engines showed that at least 90 per cent. of the total fuel was fired with the stoker, counting everything, and in many cases no hand firing whatever was needed. This would illustrate the reduction in physical labor of the firemen, and, as the fire door is open very little, the heat in the cab is so reduced that the fireman can follow the locomotive trip after trip, almost, if not quite, as regularly as the engineer. Another rather interesting advantage came with the use of the stokers on these engines, in that since the tonnage rating has been raised for those that are stoker-fired there is great rivalry as between hand-fired and stoker-fired engines of the same class, and within the past year or eighteen months the rating of the hand-fired engines has been materially increased, but, as this has been raised, the tonnage rating on the stoker-fired has also been still further in-

creased until on some divisions it is now one thousand tons per train more than was given the hand-fired engines before any stoker engines were received, and is still at least 500 tons higher than any hand-fired engine.

It was also found not practicable to run shovel-fired and stoker-fired locomotives on the same division, even with the less tonnage, as the speed of the hand-fired was so much less that they could not keep out of the way, and now all trains on the different divisions are generally either stoker-fired or hand-fired. In one case, on three divisions adjoining making a total distance of something like 450 miles, all of the freight power is stoker-fired.

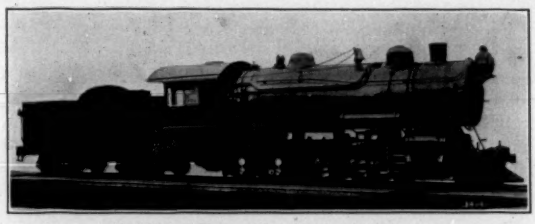
Chesapeake and Ohio Mikado.

This is one of the largest Mikado locomotives in service to-day, having a tractive effort of 60,000 pounds and a grate area of 66.7 square feet.

In answer to the question, "What size or class of locomotives should have stokers?" it can be said, first, that under average conditions any locomotive, freight or passenger, which has a maximum tractive effort of 50,000 pounds or burns 4000 pounds or over of coal per hour for an extended period, one hour or over, should be fired with the stoker.

This locomotive was designed on the basis of requiring approximately 120 pounds of coal per square foot per hour for its maximum capacity, or about 8000 pounds per hour. This, with a tractive effort of 60,000 pounds, would then theoretically bring this locomotive well within the stoker class. In practice this also proves correct, as on a certain division equipped with these locomotives the stoker-fired rating is 6000 tons, and if, for any reason, the stoker should be inoperative, the official rating is 4800 tons. Fifty of these locomotives were equipped with Street stokers during the summer of 1912, and they therefore have been in service long enough to secure records of mileage per mechan-

ical failure, cost of maintenance, kind of coal suitable or available for stoker firing, and dynamometer car tests have been made which confirm the above statements as to comparative rating possible between stoker- and hand-firing.



Norfolk and Western Class M-2 locomotive.

This photograph is of interest as showing one of the smallest locomotives to which stokers have been applied. The tractive effort is 52,400 pounds and there are but 44.7 square feet of grate area. This is one of the locomotives on the Norfolk and Western that was used before the arrival of the Z-1 and Z-1-A Mallets, which are now hauling nearly twice the tonnage this locomotive was able to handle. The grate area of this locomotive is rather small for the boiler plant, and therefore it is a hard locomotive to fire as compared with others of similar size, and stokers have been applied to some fifteen or twenty of them—four or five Street stokers and twelve or thirteen Standard stokers. In this particular case the necessity for the application of the stokers might be questioned, although the engines can undoubtedly be worked harder and much relief is afforded the fireman from labor and heat.

Photograph of Virginian Mallet.

This is the largest road Mallet engine ever built, having a tractive effort of 115,000 pounds and a grate area of 99.2 square

feet—the latter about the same as the Baltimore and Ohio Mallets. Six of these locomotives are in service, all being fired with the Street stoker.

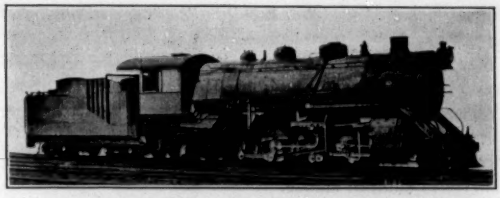
When these locomotives were built, some three years ago, the mechanical stoker was not enough of a certainty to warrant the use of a firebox longer than eleven feet, whereas it is, I think, a safe prediction that eventually locomotives of this size and larger will be designed to be stoker-fired and have fireboxes with grate area nine feet wide and fourteen or fifteen feet long, eleven feet being the admitted limit for hand-firing.

I am showing you practically all of the stoker-fired locomotives that there are, and all of them were designed to be both stoker- and hand-fired, which set limitations that will disappear later on.

Photograph of El Paso and Southwestern Consolidation.

This locomotive is shown in this series particularly on account of size. It is just the opposite of the one last shown, and is about the smallest to which any number of stokers have been applied to date. The tractive power is 49,988 pounds and the grate area 49.5 square feet. Twenty-one of the locomotives are being fired with the Street stoker, mainly on account of the climatic conditions in the desert country of Southern Arizona, which makes it impossible for the firemen to, at all times, fire even this rather small locomotive to its maximum rating.

This is another very large Mikado locomotive. The first installation in the Western territory of mechanical stokers to handle the mine screenings from Illinois coal fields was made on thirty-five of them by the Chicago, Burlington and Quincy Railroad early last year.



Photograph of Chicago, Burlington and Quincy Mikado.

It was found possible to use screenings from nearly all of the mines, and at the same time secure the very satisfactory tonnage increase of from 500 to 700 tons per train over the same locomotive hand-fired.

Photograph of Pennsylvania Lines H-10-S Consolidation.

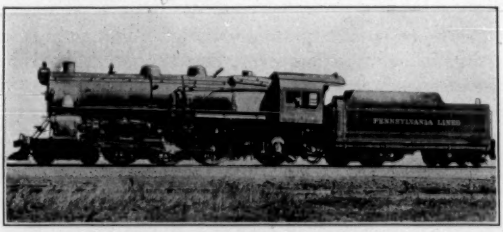
This locomotive is of particular interest as having the Crawford underfeed stoker on over three hundred of them.

It is what might be called a medium-sized locomotive, having 55.12 square feet of grate area, 26 x 28 cylinders, 229,900 weight on drivers, and a rated tractive effort of 50,069 pounds. This latter is a low figure on account of the factor of adhesion used in determining it, being something like 4.95 or 5 as compared with 3.9 to 4.2 usually taken. As a matter of fact, this was taken advantage of by increasing the cylinders from 24 x 28 to 26 x 28 when it was found that the boiler plant could be forced enough harder with the stoker to supply steam for the increased cylinder volume.

The coal supplied for stoker-firing is the same as used on the

hand-firing power, the stoker handling the large lumps by crushing as explained.

Three great advantages have accrued to the Pennsylvania Lines West from the application of this large number of stokers to this class of power. The locomotives have an increased tonnage rating, the firemen are relieved from a large part of their labor and suffering from the heat, and a considerable reduction is made in the amount of smoke.



Photograph of Pennsylvania Lines Pacific K-3-S.

This locomotive represents the largest installation of mechanical stokers on passenger power, nearly one hundred of them being equipped with the Crawford underfeed stoker.

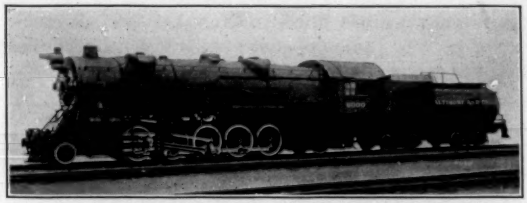
Only eight other passenger locomotives in this country besides these have mechanical stokers.

This locomotive is not a large one for stokers, having cylinders 26 x 26, weight on drivers 190,000 pounds, and grate area of 55.4 square feet, about the size of the Consolidation just shown.

So far as my observation has gone, it would lead me to say that this locomotive and the service in which it is used together make nearly ideal conditions for use of the underfeed stoker.

When a heavy through train leaves Union Station, Pittsburgh, going west, pulled by one of these locomotives, stoker-fired, the work is at a very uniform rate for 188 miles. A very satisfactory balance can be struck between the intervals required for the coking process and the total quantity of fuel required to keep the steam at proper point so that all the benefits of the underfeed scheme of firing are secured, such as capacity, economy, smoke elimination, and the improvement in the fireman's job.

We now come to a type of locomotive that is receiving marked attention by railroad companies, especially since the mechanical stoker became a commercial possibility.

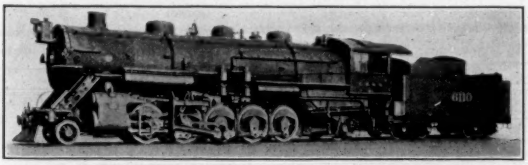


Photograph of Baltimore and Ohio Santa Fé type.

I do not believe it would be claiming too much for the mechanical stoker to say that thirty of these locomotives, on the Baltimore and Ohio, having a tractive power of about 80,000 pounds, cylinders 30 x 32, and grate area of 88 square feet, would not have been built to be hand-fired.

Street stokers were applied by the Baldwin Locomotive Works to the entire lot when built last year.

These are about the largest simple locomotives ever built.



The Chicago, Burlington and Quincy M-2 Santa Fé type.

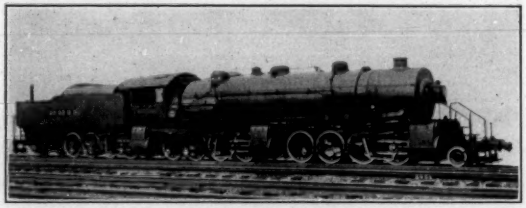
This locomotive is of special interest as being the very first designed, as to arrangement and dimensions, to be stoker-fired, and is of the same general dimensions as the one just shown, having cylinders 30 x 32, grate area 88 square feet, tractive power of 72,800, and weight on drivers of 301,800 pounds.

Designed in 1911, built in 1912, it was, even at that time, admittedly beyond the physical limits of hand-firing.

The first five of these locomotives were equipped with the Barnum stoker, the first stoker described in this paper. These

were later removed, and the Street stokers are now on twenty-seven in service and being applied to fifteen more at the Baldwin Locomotive Works this month.

In daily service these locomotives burn an average of 5500 pounds of slack coal per hour, and for short periods each trip at the rate of 9000 to 11,000 pounds per hour, which well illustrates their being beyond the limits of hand-firing.



Erie Triplex locomotive.

This Erie locomotive, designed by Mr. G. R. Henderson, of the Baldwin Locomotive Works, has received a great deal of comment. It has such new and novel features that it is out of the ordinary.

It is commonly referred to as a Triplex locomotive on account of its having three sets of driving wheels—is three locomotives in one, in fact, and has a tractive power rating of about 160,000—the highest of any locomotive ever built.

The grate area is about the size of the Baltimore and Ohio and Virginian Mallets which we have seen.

Designed to take the place of at least two other locomotives in pusher service on the Susquehanna grade on the Erie Railroad, it requires about 10,000 pounds of mine screenings per hour to fire it to its maximum rating, possibly a little more under certain conditions. It is fired with a Street stoker and is in daily service, doing the work successfully.

In a published interview regarding this locomotive, Mr. S. M. Vauclain, vice-president of the Baldwin Locomotive Works, makes the following statement:

"This type of locomotive would never have been suggested, however, were it not for the fact that we are now able to feed a locomotive boiler any amount of coal up to its capacity to burn

it. Thus the human equation heretofore preventing the use of large power units has been overcome, and it is my belief that we are just beginning to enter the field of large power units for freight service of the trunk lines of this country. If it can be proved that we can operate locomotives of 150,000 pounds tractive effort with the same engine crew as heretofore and with less physical exertion on the part of the fireman than with the locomotive of only 50,000 pounds tractive effort, it would appear reasonable that such units of power will be in demand, not only by the railroad companies but by the employees as well."

The fact that more than 1000 locomotives such as I have shown you are being fired with mechanical stokers ought to prove conclusively that the mechanical stoker is no longer an experiment and that it must have some economic value to warrant its application to so great a number of the largest modern locomotives.

What contributes to this economic value?

The use of slack coal or mine screenings for locomotive fuel, for one thing, has a share in it.

We now have enough information about the value of different kinds, grades, sizes, and physical characteristics of coal for locomotive fuel to state positively that the physical characteristics of coal are more important than the chemical analysis. Better results are often secured from coal of inferior quality, but of proper physical form than from that of a better grade in improper size; the variation of evaporation in pounds of water per pound of coal, due to such differences, being identical whether fired by hand or with a stoker.

If, therefore, by the use of a mechanical stoker, all kinds of coal that can be used for hand-firing can be used for stoker-firing with equal economy, and also other kinds and grades of coal become available for locomotive fuel that could not be used for that purpose, the stoker should be given credit for the economic value of a wider market being found for what is a by-product in many districts.

The stoker as a labor-saving device is also of great value not only in the reduction of physical labor and suffering of the firemen, but generally raising the grade of that class of employment, and, while this would not bring about, of itself, a general use of stokers on locomotives, it has its value in the general proposition.

The firemen themselves, as a rule, are favorable to the stoker.

The locomotive engineers, while ordinarily having no interest in the stoker, are just now very much in favor of it.

On one railroad employing nearly one thousand firemen the traffic conditions are such that it has been necessary to "set back" a large number of engineers; that is to say, they must temporarily take the fireman's side of the locomotive, the firemen either being laid off or put on the extra list. Engineers who have not fired a locomotive for several years have a hard time firing under such circumstances: first, because of their physical unfitness, and then, too, because when they served their time firing the locomotives were much smaller than at present. If there is a stoker-fired locomotive on their division and their "rights" entitle them to it, they surely see that arrangements are made for them to be called for the stoker.

The firemen can follow their runs with the same regularity as the engineers on stoker-fired locomotives, and this brings practically the only real criticism the men have against the stoker; that is, that less extra firemen are required in any given district than for hand-fired engines.

The firemen on stoker engines usually make more mileage per month than when hand-firing, with the consequent increase in size of pay check.

As for the need of a second fireman or helper on stoker-fired locomotives, it is now admitted by all, even the officers of the firemen's organization, that where stokers are in successful operation there is no need of—in fact, no demand will be made for—an additional man as asked for on large hand-fired power.

The stoker must eventually have the effect of inducing a better class of men to take up the locomotive firemen's trade. Certain railroad officials consider this tendency, already noted where large numbers of stokers are used, as of great importance.

In searching for all answers to the question, "What is to be gained by the use of mechanical stokers on locomotives?" the really important consideration is that a locomotive is the only thing on a railroad that earns money, and if the stoker can and does remove the limit which is set to the capacity of large locomotives by the inability of the fireman to fire them to their maximum capacity, especially for long periods, then something has been done of economic value not heretofore accomplished.

A brief explanation of why it is almost impossible to hand-fire a large locomotive to its absolute maximum capacity may be of interest here.

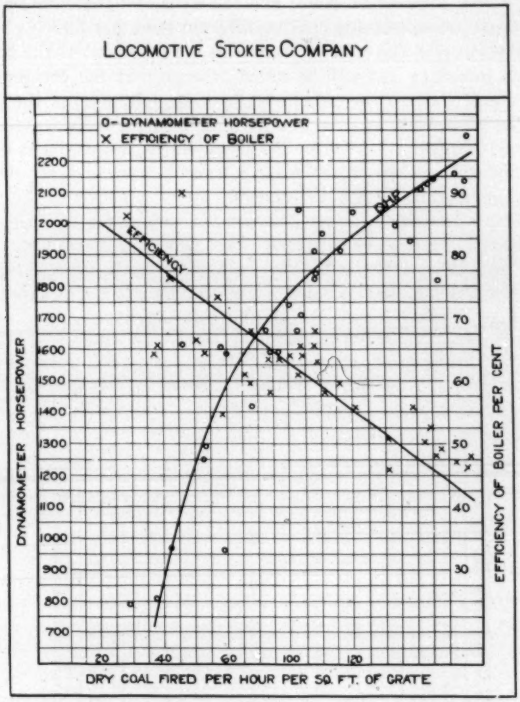


Diagram illustrating boiler efficiency and dynamometer horse-power at different rates of firing.

It is not generally appreciated that the boiler plant of a locomotive differs in many respects from that of a stationary power plant.

The over-all dimensions of a locomotive, which are largely governed by road clearances, centre of gravity, etc., make the firebox of such size, even the largest permissible, that the rate of

combustion per square foot of grate area per hour is several times that of a stationary boiler.

This is a diagram illustrating the relation between the efficiency of a locomotive boiler and the dynamometer horse-power developed when burning coal at different rates per hour.

The drop in the efficiency curve is very marked as the horse-power increases. It will be noted at once that the per cent. of boiler efficiency drops off almost in a straight line as the locomotive is worked harder. This will illustrate why it is more difficult in proportion to fire a locomotive as the engineer opens the throttle and drops the reverse lever "over amongst the oil cans," as the enginemen term it.

The average fireman usually is at his limit when the firing rate reaches 75 pounds per square foot of grate area per hour.

The curvature of the dynamometer horse-power line is brought about by the decrease in the amount of water evaporated per pound of coal as the combustion rate increases.

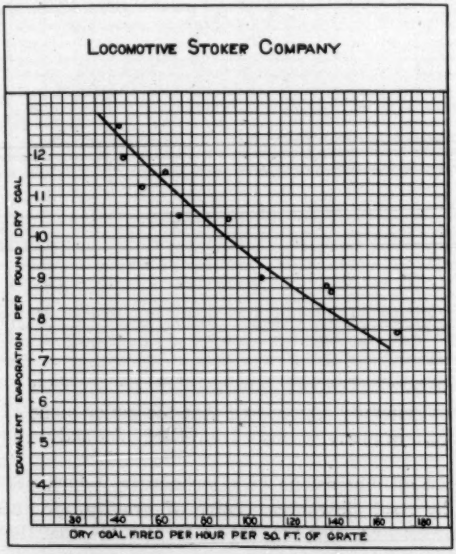


Diagram showing evaporation at different rates of combustion.

This diagram will illustrate the rates of evaporation as the coal fired per square foot per hour increases.

This will also explain why it is sometimes said that a stoker-fired locomotive burns more coal than hand-fired. It does, usually, because worked harder, and it takes more coal to evaporate a pound of water at the point where stoker-fired locomotives are worked.

Illustration of stoker conditions in a mountain district.

All large locomotives are not now in a service requiring stokers. On the other hand, there are large numbers of rather small locomotives that are in use where larger locomotives, stoker-fired, could do the work more economically from every point of view. This is an illustration of such a condition: Five hand-fired locomotives on one train, worked hard and not well fired, either, if appearances count for anything.

Larger locomotives can and will be designed, two of which could handle this train.

Locomotive capacity then seems to be the real point in the stoker proposition, even at the expense of some economy in the amount of water evaporated per pound of coal, and what this

means in increase of earning power of a locomotive as compared with any increase in cost of coal as the consumption increases per square foot of grate area per hour is illustrated on this diagram.

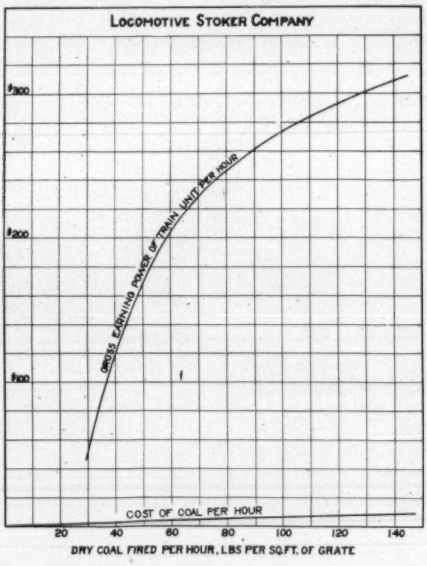


Diagram showing increase in earning power of locomotive as it is worked harder.

It will be seen at once that the increase in earning power is of vast importance as compared with the slight rise in the line showing the coal cost as the locomotive is worked harder.

These curves were plotted from statistics showing freight train earnings when handling such commodities as coal, ore, limestone, etc.—just such lading as is in heavy drag service where stoker-fired engines are used. The coal cost was figured at $1.50 per ton on locomotive tender.

So far as I know, there is not a single case where stokers have been applied by any railroad company that there has not been a material increase in tonnage rating, and in spite of the increase in

tonnage there has usually been an improvement in the general smoothness with which the traffic has been moved on the stoker-fired divisions.

To sum up, therefore, mechanical stoking of locomotives raises the efficiency of the locomotive by increasing its earning power, raises the efficiency of labor by making it possible for one crew to handle more traffic per train unit or the same train unit with greater ease, lessens the arduous physical labor and suffering of the firemen, and lifts the grade of his employment; contributing in these and other ways such share of the improvement in the welfare of the individual and the community at large that any labor-saving device must do to be commercially successful.

DISCUSSION.

CHAIRMAN.—The mechanical stoker is the sort of device The Franklin Institute is always in sympathy with, a device that saves money and reduces human suffering to an extent that makes it possible for men to work with comfort to themselves and efficiency to their employers.

I will ask Mr. George R. Henderson to open the discussion.

MR. GEORGE R. HENDERSON (*The Baldwin Locomotive Works*).—Mr. President and Gentlemen of The Franklin Institute: I was very much interested in what Mr. Bartholomew has told us in regard to stokers, but when he says that stokers were not needed before 1912 I think he has gone a little bit too far. For several years before that there were a number of Mallet locomotives built and running in the northwestern part of this country, and when questions are raised as to the difficulty of firing, in keeping these engines hot, it was remarked that there was no trouble and the firemen took it very easy. When we examined these men at work we found it quite true that the firemen did take it easy, and that the engines took it easy. Instead of an engine of double the capacity, we had about the same horsepower delivered as with the smaller engines, simply because the firemen worked up to what they thought was the proper limit, and did not put any more coal in than they used to do on the smaller engines, thus showing the need for a stoker as early as 1907.

It is interesting to note that the stoker which Mr. Bartholomew said had disappeared—that is, of the plunger type—was operating, I think, on the Chesapeake and Ohio in 1904. In 1905 there was a company organized to exploit this stoker, and, in spite of my recommendations to get it out of the cab and bring the coal from the tender by a conveyor, they refused to do any more than sell what they had—it was take it or leave it, and therefore they *left* it, and the company went to pieces.

When you consider the method of blowing coal in by steam, which is the generally-accepted method, it is interesting to note that Mr. Kincaid, in one of his early patents (1909), covered that feature, but I do not think he made any application of it to a locomotive.

MR. A. N. WILLSIE (*Chairman, Fuel Economy Committee, C. B. & Q. Railroad, Chicago*).—Mr. Chairman and Members of The Franklin Institute; I appreciate the privilege of being present at this meeting.

I have had practical experience with but one kind of stoker, and that is the Street over-feed stoker. We have sixty-three of these in service on the Burlington road, and some twenty-five or thirty are being applied to new engines.

The time has come when it is necessary to have mechanical stokers on some of the heavy engines now in service and engines that are to be built. While it may be possible to fire these engines by hand, it is not possible to get the maximum amount of work out of the engines, but with the mechanical stoker this is possible.

I am told by men who have had experience with the different kinds of stokers mentioned and illustrated this evening that they are all giving satisfaction, and I have ridden on passenger engines on the Pennsylvania road that were equipped with the Crawford stoker and the work was done satisfactorily.

On the road which I am connected with we have been able to increase the tonnage considerably. This is so with the Mikado type engines, with a tractive power of 60,000 pounds.

The 2-10-2 type, with a tractive power of 71,500 pounds, were designed with the expectation that they be stoker-fired.

It would be very conservative to say that not over ten per cent. of the coal consumed is necessary to be handled by the scoop; in other words, a trip where twenty or twenty-five tons of coal are consumed, not over one ton would have to be shovelled

by hand, and oftentimes a great deal less, depending upon the attention the fireman gives the fire and the feeding of the coal.

Some figures were made from actual service for the month of October, 1914, comparing stoker-fired Mikado engines with hand-fired Mikado engines for October, 1913. The average tons of the stoker-fired engines per train was 4326, of the hand-fired engines 3891, or an increase of 435 tons per train. Over a division of 136 miles thirty-one minutes less time was used with the stoker-fired engines, and these additional 435 tons were handled with a few cents less cost for coal; this saving made on account of the price of coal, the stoker engine using 85-cent screenings, while the hand-fired engines were using coal at about $1.20 per ton.

The 2-10-2 type of engines also showed in this same month as handling on an average of 5374 tons, or 1587 more than the hand-fired Mikado engines. The running time over the 136 miles was seven minutes longer than the hand-fired engine, but, as stated before, they handled 1587 additional gross tons, with an additional cost of but 71 cents for fuel.

With the stoker-fired engines it is possible to make better meeting points and get over the road so as not to be tied up on account of the sixteen-hour law. It also makes it possible for the fireman to follow the engine as close as the engineer, thereby making more money than he could possibly make if following one of these large engines hand-fired. This also gets the engine off the road, making room for other trains, and the engine is at a terminal where she can receive round-house attention. It is almost impossible to get over the road within the sixteen-hour limit with the largest type of engines hand-fired, and when the crew are tied up and take their rest wherever they can get it, the fireman especially is not fit to do as good a job of firing after that, and it is always very hard on the engine to be tied up on the road. This kind of work wears the men out, and the company cannot expect but to lose by it.

On one division of the Burlington road, where the heavy power is in service and the business drops off so that it is necessary for the young engineers to go back firing, they oftentimes take the stoker-fired freight engines in preference to hand-fired passenger engines. This results in the good of the service, for the reason that when a young engineer goes back to firing and

accepts a passenger run for a few months he is not nearly so well prepared, when he again takes the engineer's position, as he would be had he put in his firing service on a freight engine, as by firing the freight engine he is kept familiar with freight conditions, such as handling long trains and keeping up to date on train orders, etc. This is bound to result in a benefit for the division.

We have also found in one piece of territory that with the mechanically-fired engine we are able to make what we term "turn-arounds," almost without exception, each trip; that is, the crew and engine are used 72 miles and then immediately turned around, returning the same distance. This not only gets the engine back into the terminal where she belongs, gets the crews home where they wish to be, but makes it possible to make this 72-mile turn-around (144 miles) within the sixteen-hour period, which saves over $10 in wages, and figures show a saving of over $7.50 in the cost of coal per trip. A great deal of this saving is caused by the engine not having to be herded around the clinker-pit tracks, fire knocked out, new fire built, and engine again delayed at terminal waiting for a train.

It is not claimed that a stoker engine will save coal over a hand-fired engine unless the engine is of such size as to make it impossible for a man to handle the coal if the engine is worked to her full capacity.

Another point in favor of the stoker engine: There may be conditions where the business has outgrown the present size of locomotive hand-fired, but in order to put in service the largest locomotives it would require many changes in the operating department, such as heavier rail, heavier bridges, larger turn-tables, addition to round-house, and numerous other items.

If the engines in this territory are of such a size as to be up to the limit of hand-firing, it may be possible that the same engine can be equipped with a stoker and get from 10 per cent. to 15 per cent. more efficiency from her. This might result in the engine being handled without any additional expense, as above mentioned. It might make it possible to handle the business over a single track, which would naturally require some double-tracking to handle the same volume if the engines were not equipped to do more work.

I feel quite confident that after the men become more familiar with the stoker-fired engines they will do a great deal better in

the matter of fuel economy. On account of the engines being fired with the door closed, it is but natural that they should save coal.

With the stoker-fired engines, also, the fire, as a rule, is so much thinner than hand-fired engines that better combustion is bound to take place, for the reason that oxygen, which is very necessary, comes up through the fire and the air is heated before it comes in contact with the gases, which will naturally make much better combustion than cold air coming in volumes over the fire and through the door when the engine is hand-fired. This light fire will also save delay and expense at terminals, requiring less time to clean the fires.

As stated above, it requires a good fireman to handle the stoker economically, as well as hand-fired, and he is relieved of so much of the physical labor that the railroad company can well afford to insist that he do his stoker-firing properly.

With hand-firing, and with the largest type of engines, the men are inclined to put in too much coal at a time. The door being opened so much not only chills the firebox, but the amount of coal thrown in chills the fire, and it requires some time before the proper heat is again obtained; in other words, it takes about 1200 degrees of heat to distil the gases from the coal, and if the temperature is not up to 1800 degrees the gases cannot burn. Consequently they are taken out through the flues and out of the smokestack unconsumed, or, in other words, just that much heat is lost, and, as the volatile matter of most of the bituminous coal ranges from 25 per cent. to 35 per cent., this waste is enormous. By the door being kept closed and the air necessary for combustion coming through the fire, it seems to me, should result in a great saving.

DR. ANGUS SINCLAIR.—Mr. President and Gentlemen of The Franklin Institute: I am very glad to be here to-night and to have heard that very interesting paper on the mechanical stoker. I have had a great deal of railway experience, and much of my time has been devoted to improvements in firing locomotives.

I began railway service in 1856 with the locomotive superintendent who first applied a brick arch to a locomotive. I was brought into close contact with that invention shortly after it was brought out, and I have always paid particular attention to

combustion, and especially to smoke prevention, which means proper firing and proper combustion.

During my time in connection with railways I have seen nearly all inventions of any consequence that have been brought out for improving the operation of the locomotive, and I have never seen anything yet brought out but what there was considerable opposition to its application. Any of you older members who can go back in your minds and follow the various inventions have seen how viciously the new things were opposed. Take the injector, for instance, and follow up other good inventions: they were bitterly opposed at the start. The locomotive men of all the companies that I am acquainted with are particularly conservative, and they object to putting something new on the engine, something that they are not accustomed to, and I think that is the secret—that there has been so much opposition to every improvement.

I have had some experience in running and firing locomotives. I ran locomotives for twelve years, and I always felt satisfied that some mechanical means of firing would be invented and perfected. It is some ten or twelve years, I think it must have been, since I first heard about the mechanical stoker, and I felt so much interested in it that I rode on the engines using them. My judgment of that first stoker was that it was rather imperfect and showed rather crude invention, but it seemed to be capable of improvements that would make it just as successful a device as the injector proved to be. However, the parties who had hold of that seemed to get discouraged at the first opposition. The enginemen were by no means enthusiastic about it. I heard that they expected ordinary laborers to be on the engines to do the work, and that the fireman's job would be at a finish, and my experience with the successful mechanical stokers has been that it requires a more intelligent man to operate the stoker as it should be operated than it does a man to shovel the coal, and I think that as the experience develops with the mechanical stoker it will be much more efficient than it is to-day, and the improvement that comes with practice will still add to this efficiency and therefore add to the economical operation of the mechanical stoker.

I have had quite a busy life. I have ridden on engines equipped with the stoker; I have been on several of them—on the

Street stoker particularly; and I do not think there is any mechanical device in use that works more successfully than it does.

When they talk about waiting for developments of the mechanical stoker, they are talking about something they do not understand. It is as well perfected as any ordinary device, and it will be successful when it is in the hands of its friends.

MR. W. L. ROBINSON (*Baltimore and Ohio Railroad*).—I came in a little too late to hear the entire paper read. We have 222 of these locomotives operating successfully in regular service, and, from what Mr. Bartholomew has read and shown you, there is not much left to say, due to a great deal of what has been stated applying to the operation of the Street stokers on the Baltimore and Ohio. However, I had the opportunity to read the paper carefully before coming to the meeting, and will say that, in so far as the experience of our road is concerned, Mr. Bartholomew has covered the matter very well.

Mr. Willsie has also spoken of the main advantages of mechanical stoking, and there are only one or two things I would care to mention in addition to what has been stated, and they are the question of increased train load and method of carrying the fire on the grates.

In regard to train load, it should be stated that this has increased from eight to fifteen per cent., and the stoker locomotives get over the road very much better and bring about a more uniform performance.

Regarding the method of carrying the fire on the grates, it has been necessary to carry a light, level, and bright fire to get the best results, and this has resulted in very little necessity for grate shaking, raking fires, or dumping ash pans; and I have ridden a great many engines during the past winter when trips were made with full tonnage trains and the fire not shaken or touched by rake or ash pan dumped from one end of the road to the other, and the fire in such condition that full steam pressure was maintained to completion of trip.

All these locomotives are operating in pool service, except on one division where they have recently been assigned to regular crews.

I think about all of the features have been well covered, and it is merely repetition to add to the remarks which have already

been made, so far as Street stoker is concerned, and I have had no practical experience with any other type of over- or under-feed stoker.

CLOSURE BY AUTHOR.

From what has been stated in the paper and by those taking part in the discussion it is no doubt very plain that the mechanical stoker for locomotives does not come within either of two classes of labor-saving devices which were referred to earlier in the evening; *i.e.*, those which are applied entirely for the profit to be made on the investment or those which are applied entirely for humanitarian considerations.

It is evident that the railroad companies and the enginemen both profit by the application of mechanical stokers to locomotives.

Locomotive capacity is increased, while, strange as it may seem, the fireman's labor in shovelling coal and his suffering from the heat are materially reduced.

The railroads secure a return on their investment from the increased tonnage, less expensive fuel, and other economies effected, and the men, individually, make more money per month with less effort.

Small locomotives are made larger, and larger locomotives are made possible.

These and other results are being accomplished by stokers designed to be applied to existing power with the necessary limitations that come thereby, and much more may reasonably be expected in the future, now that the stoker has established itself for permanent use, as stokers will be taken seriously into account in the designing of new heavy power to be built in the future for capacity as well as economy.

The Franklin Institute deserves great credit and the hearty thanks of the railroads, the public, and the men who fire the locomotives for the interest taken in the development of devices of this kind which serve the double purpose of contributing to the uplift of the men who work and at the same time have economic advantages sufficient to warrant the necessary investment for their general application.

ON AN UNBROKEN ALTERNATING CURRENT FOR CABLE TELEGRAPHY.*

BY

LIEUT.-COLONEL GEORGE O. SQUIER, Ph.D., M.R.I.,

Fellow of the Physical Society of London,
Member of the Institute.

I. *Introduction.*

THE object of this paper is to propose a new angle of view in the method of transmission of signals in the submarine telegraph cable, and to describe some apparatus for operating on the general principles involved.

Although more particularly an engineering subject, yet it is brought before the Physical Society in the hope that some of its members may see in the plan proposed some points in the fundamental theory of ocean cabling for further research.

The phenomenal progress of wireless telegraphy has been made possible only by the combined efforts of some of the world's best-equipped physicists and the practical engineer. It is in the hope of a similar coöperation of effort for the advancement of cable engineering practice that I invite your attention at this early stage of development.

Experiments have been conducted during the past two years at the works of Messrs. Muirhead & Co. (Ltd.) with a view of determining the practical application of the sine-wave type of E.M.F. for cable signalling. The results thus far obtained have only been made possible through the wide range of experience and practice which this distinguished firm of cable engineers have been able to bring to bear on the subject, and they have taken a leading part throughout the experiments carried out.

Sixteen years ago Dr. Crehore and the author conducted some experiments on an Atlantic cable from Waterville, Ireland, to Nova Scotia, Canada, using a special form of dynamo as a source of power for operating the cable.

A transmitter was also devised, in which a special feature was

* Communicated by Colonel Squier.
Read before the Physical Society of London, June 25, 1915.

the cutting out or suppressing from the alternating current certain definite semi-waves of current which enabled the cable code to be transmitted.

At that time the demand for increase of speed over ocean cables was not pressing. In fact, the particular cable used was idle for several hours each day, which fact, however, greatly facilitated the opportunities for experimenting.

Wireless telegraphy did not then exist, and the cable relay or amplifier had not appeared, so that very accurate balancing of the duplex bridge was not required.

Conditions have changed materially since 1899, until at the present moment it may be said that the matter of obtaining increased speed on ocean cables with present apparatus is largely controlled by the accuracy with which the duplex bridge may be balanced.

II. *An Ocean Cable Considered as a Power Line.*

If an engineer were required to design a system for operating an electric motor through an Atlantic cable, no form of generator could be proposed at present, other than a single-phase alternating current of the sine-wave type. This form, we know, will deliver power at the receiving end of the cable more efficiently than any other shape of wave. Furthermore, during the operation of such a motor, the generator would be allowed to run smoothly and regularly, and, in particular, the generator circuit would never be metallically opened or closed during operation.

The opening and closing of an alternating-current circuit is well known to produce disturbances of a more or less pronounced character, depending upon the angle of phase at which the current is opened or closed.

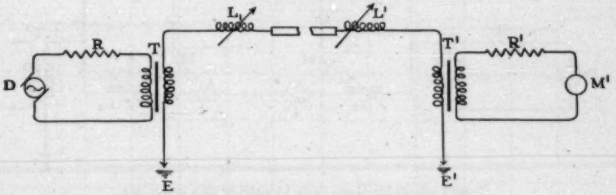
Since improvement of the duplex-bridge balance, as stated above, is really at present a most important desideratum, experiments were made using the Muirhead artificial cable to compare the present forms of battery transmitters with various modifications of the sine wave of E.M.F.

In the last analysis it was always the opening and closing of the transmitter circuit which produced the final kick or " jar " in the balance. This is not surprising when we remember that, from an electrical standpoint, few things can be done to a circuit more severe than to suddenly introduce an infinite resistance into it.

However, since there is an appreciable spark or arc at the instant of opening the battery transmitter circuit, this discharge controls to a greater or less degree the character of the break; but the exact influence of this is not so easy to predict, for, though it is probable that the current dies away quicker with a sudden break than it does with a very slow one, which permits the arc to remain for some time, yet it is not proved certainly, for the more rapidly the break is made the faster the resistance increases, and therefore, probably, the rate of change of current, and with it the counter E.M.F., increases. An increased E.M.F. can bridge a longer gap, but a longer gap may be made in the same time that a short one is, with a less velocity at the break. So it appears that these two considerations counteract each other, and it all depends upon which has the greater influence.

It was only after many variations of the simple alternating

FIG. 1.



Simplex circuit for ocean cable considered as a power line.

current had been tried in the course of experiments to perfect the duplex balance of the bridge that the fundamental principle of never breaking the transmitter circuit became impressed.

Continuing the analogy of the power plant, it may be remarked that practically every form of cable recorder, amplifier, or relay is essentially an alternating-current motor. Its field magnets, armature coil, and the counter E.M.F. of damping are subject to the same laws as in the motor for power purposes.

Let us assume, therefore, as a starting point, the standard type of circuit for operating a cable simply as a power plant as the ideal solution of the problem, and then determine by experiment how near this solution may be retained in practice for the purpose of transmitting cable signals according to the present alphabet. In this plan it will be the continued experimental purpose to deter-

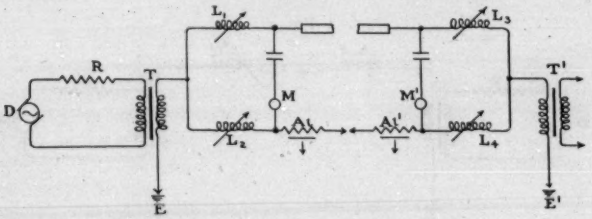
mine the minimum possible variations in such a system to enable the alternating current received to be interpreted into dots, dashes, and spaces.

A siphon recorder placed in the receiving end of such a cable plant would trace on the recording slip an uninterrupted sine wave of current which may be considered as the theoretically perfect form of siphon record always to be aimed at, although never to be actually attained in practical telegraphy.

In Fig. 1, D represents a single-phase alternating-current dynamo, R and R' are resistances, and M' is a motor to be operated.

Since a circuit comprising an ocean cable is largely overloaded with capacity, and already includes a large ohmic resistance, it will be in the direction of increasing the resultant harmonic current flowing in such a circuit, to insert in the sending end of the cable a

FIG. 2.



Duplex circuit for ocean cable considered as a power line.

variable inductance, L_1. For symmetry, L' is a variable inductance similar to L_1.

T and T' are iron-cored transformers or auto-transformers, the coils of which are of low resistance, and connected directly to earth at E and E'.

The circuits in Fig. 1 are closed circuits throughout.

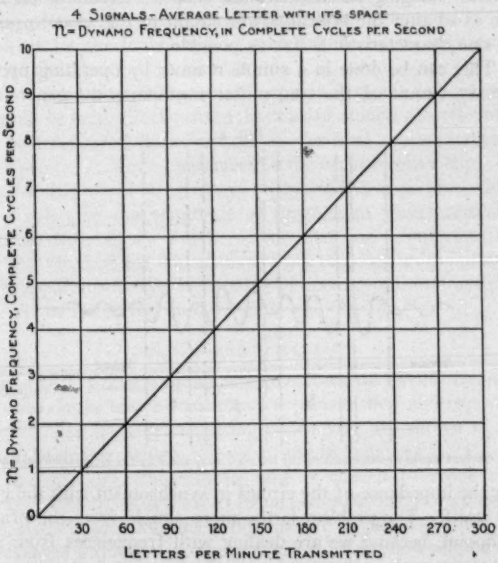
For duplex working Fig. 1 becomes Fig. 2, in which L_1, L_2, L_3, L_4 are the inductance arms of the bridge, and the motors M and M' are inserted in the usual manner for cable working; Al and Al' are the artificial lines.

It now remains to inquire as to what modifications must be made in the typical duplex power circuit in Fig. 2 to enable the motor recorders to indicate the elements of the cable alphabet. These elements are three in number, and only three—*i.e.*, the dot, the dash, and the space—and each of them is equally important in

interpreting the record, and for this reason they will each be considered in the general sense as signal units, rather than the usual way of regarding only the dots and dashes as the signals, and not the spaces.

It is also usual to speak of cable speeds in terms of standard letters per minute transmitted; but for our present purposes it will be more convenient to convert this speed into terms of the fre-

FIG. 3.



Speed of cable signalling in letters per minute in terms of the frequency of the alternator.

quency of the dynamo. The graph (Fig. 3) exhibits the linear relation between n, the frequency of the dynamo, and letters per minute transmitted, based on the assumption that the average cable letter, with its space, requires four units of alphabet time.

Careful experiments on an Atlantic cable confirm the theory of the subject—that, no matter what the shape of the alternating current transmitted, approximate sine waves are received at the distant end of the cable. Battery reversals produce just as accurate

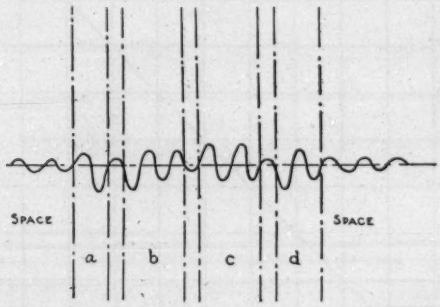
sine-wave signals on the receiving recorder as does the alternator itself.

In other words, it is the fundamental term of the Fourier analysis which is alone concerned in making the record at the receiving end of the cable.

Since, therefore, both theory and experiment show that a sine form of wave is the only one which can pass through the cable without changing its characteristic shape, it should be an advantage to so alter the typical power circuit in Fig. 2 as to preserve the sine characteristic as far as possible.

This can be done in a simple manner by operating upon the primary circuit of the transmitter containing the generator, to

FIG. 4.



Current waves for transmitting the letters *a*, *b*, *c*, and *d* by the alternating current.

alter the impedance of the circuit in synchronism with the generator itself. The problem is the more simple from the practical standpoint, because we are dealing with frequencies from about four to ten cycles per second, and, therefore, it is easy to operate with great accuracy on this primary current at any angle of phase. If the change of impedance of the primary circuit always takes place at the instants when the current flowing in the circuit is naturally zero, the fundamental frequency of the current will not be changed, and the sine characteristic of the wave will be very approximately maintained. Varying the impedance of the primary circuit will change the amplitude of the individual alternations of the current.

Another way of stating the effect is that the voltage between the end of the cable and the earth is made to vary by this process, to indicate the three elements of the cable alphabet. It should be noted that this plan transmits alternating current for the spaces between letters and words with exactly the same regularity and integrity as for the signals themselves.

Dots, dashes, and spaces are each transmitted by impulses of either sign, differing from each other only in amplitude.

Fig. 4 shows diagrammatically the form of current waves transmitted for the letters *a*, *b*, *c*, and *d* with the accompanying spaces required.

Although an alternating current operated upon as above outlined could be read directly from a standard siphon record, yet it would be considered an advantage if the final received record could be printed in Morse characters on the usual receiver slip. To accomplish this it will be necessary to provide an apparatus which operates solely by the amplitude of the current waves received, and not by their sign. Furthermore, since the impulses transmitted and received for the spaces are not required on the printed slip, the apparatus should be capable of sorting out and omitting these parts of the record automatically.

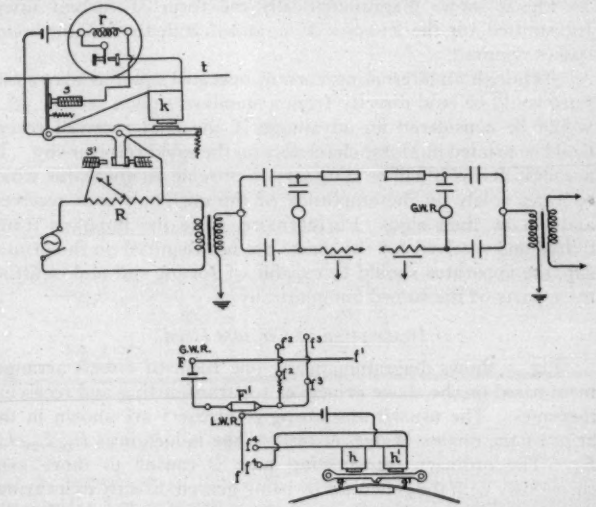
Description of Circuits Used.

Fig. 5 shows diagrammatically one form of circuit arrangement based on the above principles for transmitting and receiving messages. The usual transmitting condensers are shown in the arms of the duplex bridge, instead of the inductances L_1, L_2, L_3, L_4. The ordinary transmitting tape is caused to move synchronously with the generator by being geared directly to its armature shaft. The perforations in the tape are of such a size that the tape advances a distance corresponding to one semi-cycle of the alternator for each individual perforation.

Since in a circuit comprising an ocean cable on which is impressed an alternating E.M.F. the current leads the E.M.F. by an angle which in an infinite cable is constant at 45°, it is necessary to provide in the transmitter mechanism for moving the tape carriage longitudinally relative to the perforations in the tape. A micrometer screw is provided for this purpose, and by its use the current can be operated upon accurately at any angle of its phase, and in practice it is so adjusted that the impedance of the

primary circuit will be changed at the instants of zero phase of the current. Since also the angle by which the current leads the E.M.F. is dependent upon the resistance of the primary circuit, there is also provided in addition an adjustment of the transmitter for the very slight difference of phase for the dot-and-dash conditions, so that in effect all operations on the primary current, whether for a dot, dash, or space, are adjusted to take place at the zero point of current.

FIG. 5.



One form of duplex circuit arrangement for transmitting and receiving messages by the alternating current.

The general operation of the transmitter mechanism is as follows: When no holes are perforated in the tape *t*, the whole resistance *R* is in the primary circuit and an alternating current is transmitted, which corresponds to spaces between letters and words, and when a perforation in the tape is on the dot side, part of this resistance *R* is short-circuited, and when a dash perforation occurs, all of this resistance is short-circuited. The relative values of these resistances being adjustable, the amplitude of the individ-

ual alternations is under complete control by the ordinary transmitting tape.

In the figure is shown diagrammatically the arrangement for causing a dash impulse to be sent by the transmitter by short-circuiting the whole of the resistance R for a time corresponding to one semi-cycle of the alternator. r is an ordinary relay, k is an electromagnet which operates at the end of each signal or group of signals. The line l leads to an exactly similar arrangement which is provided for the dot impulse by which a certain proportion of the resistance R is short-circuited. In practice these two arrangements are side by side, and in the figure the dot arrangement would be immediately behind the one shown for the dash.

The tape carriage can be moved longitudinally by a micrometer screw which is not shown in the figure, and has an adjustment over a range of a complete semi-cycle. The contacts s and s', and similar ones for the dot mechanism, are adjustable by slow-motion screws, so that the instants of contact for a dot and dash have an adjustment relatively to each other.

A convenient method of observing the wave-form produced by the transmitter, and for making the above adjustments, is to include an ordinary siphon recorder in the transmitter circuit, or, better, in the cable itself at the transmitting end; by connecting it at the terminals of a very low resistance in the circuit. At the very low frequencies involved, the siphon recorder becomes a most useful and accurate current curve-tracer, and enables the experimenter to observe exactly the shape of wave being transmitted into the cable for any adjustment of the transmitter. Once these adjustments are made for any particular cable they remain unchanged.

Form of Receiving Circuits.

One practical arrangement for receiving the signals on a Morse printer is shown diagrammatically in the upper part of the figure.

F is an adaptation of the well-known Muirhead gold-wire cable relay, in which f' is the gold wire which oscillates between the platinum contact posts f^3f^3, about a fixed point at F. A second pair of posts f^2f^2 is provided, and each of these pairs has an adjustment for altering their distance apart and also for moving them longitudinally along the gold wire and relatively to each other. Instead of being separate contacts, as in the usual case

with this relay, each of the pairs are electrically connected as shown. F' is a local wire relay of similar principle, and f is its moving part which in its oscillations makes contact with the posts f^4f^4 adjustable as above; h and h' are electromagnets for operating the dot and dash arms of the printer; g and g' are two arms pivoted at their outer ends, adapted to make a siphon record at their free ends in the centre upon the moving tape shown beneath. The arm g' is forked to record two ink marks on the tape symmetrically on either side of the central mark made by the arm g, and in line with it across the tape, so that both arms can make a record simultaneously on the tape for a dash.

The incoming alternating current thus causes the gold wire f' to oscillate back and forth with different amplitudes depending upon whether dots, dashes or spaces are being received, and the posts f^2f^2 are adjusted so that the space amplitude just does *not* make contact, but does make contact for a dot amplitude of either sign. In like manner the posts f^3f^3 are adjusted so as just *not* to record a dot impulse, but to make contact for the larger amplitude of a dash of either sign. It is seen that both a dot and a dash contact are made whenever a dash amplitude is received. The flexible gold wire f' in its motions about F first strikes the posts f^2f^2, and there is a bending or wrapping effect produced in the wire, which for the stronger dash impulses causes contacts with f^3f^3 also. The relay F' operates similarly through a moving arm, making contact with the posts f^4f^4 separately or both together, depending upon the amplitude of its swing.

The printer itself becomes an apparatus of marked simplicity, and is nothing more than two small siphons adapted to mark on the slip in the usual manner.

In practice, all adjustments are so made as to provide for transmitting for the spaces as large an amplitude as possible instead of as small an amplitude as possible, in order to approximate more nearly to the ideal electrical conditions for transmission through the cable itself.

In case a cable magnifier such as the Heurtley instrument is used instead of a gold-wire relay, it would be inserted in Fig. 5 in the recorder arm of the bridge, and operate a local wire relay and printer instead of the usual recorder. Since the relay operates on difference of amplitude of the waves, and not on their absolute

value, a cable magnifier would serve to exalt the value of this difference and furnish a greater margin for practical working.

Resolving Power or Definition.

The ideal alphabet to employ in cable signalling would be one in which, other things being equal, each letter had the same limit of legibility; because if this is not so, the speed of signalling is lowered to meet the legibility of certain letters only. In present cable practice, what may be called the "resolving power," or the definition, is not equal throughout the letters of the alphabet.

Letters like "a" or "n," for instance, may be considered as perfect letters, and whether sent by one complete cycle or E.M.F. of a dynamo, or by two square-topped waves of equal area and opposite sign separated by a time interval, produce on the siphon record approximate sine waves. On the other hand, letters like "s" or "h," where three or four square-topped waves of the same sign are sent into the cable consecutively, the received record at high speed fails to resolve these separate impulses, and the siphon record becomes a more or less continuous hump of large amplitude, which the expert operator learns to read without being able to detect the individual impulses; in fact, some practical operators seem to prefer these letters to what are known as "cross-letters," such as "a" and "n."

Careful experiments have been conducted through long cables, which prove, however, that the so-called "cross-letters" have a superior legibility, which obviously should be the case from theoretical considerations only.

We may consider the siphon record of an uninterrupted alternating current as possessing 100 per cent. definition, independent of the frequency, the voltage employed, or the particular cable used, and regard it as the standard of definition for all signals. Indeed, such a record is, in fact, a message composed of a series of the letter "a" joined together without spaces between.

In present practice it is found necessary to insert a receiving condenser in series with the recorder coil, or an inductive shunt around the coil, for the purpose of improving the definition of certain letters of the alphabet, such as "s" and "h," as well as to eliminate from the record the effects of earth currents of very low frequency induced in the cable.

III. *Electrical Measurements of the Cable Circuits.*

One of the chief attractions in the use of an unbroken alternating current for operating the cable is the fact that for the first time we are enabled to measure the constants of the different elements of the bridge and cable circuits employed under actual signalling conditions. Since one particular frequency is used and the current is never broken, it is necessary and sufficient to use the ordinary commercial hot-wire ammeters and voltmeters which are now available over suitable ranges.

A tachometer is attached to the dynamo armature shaft, so that the frequency is indicated continuously, and these readings, in connection with those of the ammeter and voltmeter, are all that are required to determine the impedance and phase angle of any part of the transmitter circuit, including those of the cable itself.

In the present forms a battery transmitter a square-topped wave is employed, and, in addition, it is found necessary to disconnect the battery and connect the cable to earth during a portion of each individual signal sent. The reason for this is that, in this form of wave, the cable receives a charge dependent upon the time during which the key remains closed for the signal, and when the circuit is opened it is necessary to give time for the cable to become discharged before the succeeding signal can be sent. This discharge is shown in the spark that is seen in the present form of transmitter when the circuit is broken. The percentage of time of each elementary signal during which the cable is connected to earth varies according to the cable, but in long cables it is usually about 25 per cent. of the whole time of the signal.

This means that of necessity the cable is entirely disconnected from the battery at both ends for a period aggregating six hours per day, due to the present method of sending the individual signals.

This discharge of the cable has, indeed, been turned to account for a useful purpose by the late Mr. Gott,[1] who quite recently developed a system of transmission in which the discharge of the cable is ingeniously utilized to operate the tongue of a relay, which causes the succeeding signal to enter the cable with the opposite sign.

This form of square-topped wave, when combined to make up

[1] British patents No. 10,534 and No. 22,364 of 1912.

letters and words, causes a broken and irregular form of current to enter the cable, which precludes the possibility of measuring the ordinary quantities, such as voltage, current, impedance, and phase-angle of the different elements of the circuit. This is extremely unsatisfactory from an engineering standpoint, and retards progress.

The development of the modern artificial line for simulating the action of the cable has required a large amount of patient and careful work extending over a number of years. As soon as any form of break, with its consequent spark or arc, is removed from the transmitter circuit, and an alternating current of one frequency only is substituted, the artificial line can more faithfully represent the action of the current flowing in the real cable, and its construction may be simplified.

Transmitting Impedance of an Atlantic Cable.

In the case of long submarine cables having resistance and distributed capacity, self-induction and leakance being neglected, we have the well-known sine-wave formulæ for an infinite cable:

$$e = E_\epsilon^{-\sqrt{\frac{CR\omega}{2}}x} \sin\left\{\omega t - \sqrt{\frac{CR\omega}{2}}x\right\}, \quad \ldots\ldots(1)$$

$$i = E\sqrt{\frac{C\omega}{R}}\epsilon^{-\sqrt{\frac{C\omega}{2}}x} \sin\left\{\omega t - \sqrt{\frac{CR\omega}{2}}x + \frac{\pi}{4}\right\}, \quad \ldots\ldots(2)$$

e and i represent instantaneous values of the voltage and current at any point of the cable at a distance x from the origin and a time t: E is the maximum value of the E.M.F. applied to the cable, R and C are the resistance and capacity of the cable per unit length, w is 2π times the frequency.

These formulæ are accurate for all practical purposes in the case of long cables, as will be shown presently.

At the transmitting end of the cable $x = 0$, and (2) becomes

$$i = E\sqrt{\frac{C\omega}{R}} \sin\left\{\omega t + 45°\right\}, \quad \ldots\ldots(3)$$

$$i = I \sin\left[\omega t + \theta\right], \quad \ldots\ldots(4)$$

where I is the maximum current and θ is the angle by which the

current leads the E.M.F. This angle is constant and equal to 45 degrees. The transmitting impedance of the cable is

$$Z_1 = \frac{E}{I} = \sqrt{\frac{R}{C\omega}} = \sqrt{\frac{R}{2\pi C}}\sqrt{\frac{1}{n}} = c_1\sqrt{\frac{1}{n}} \quad \ldots\ldots\ldots\ldots (5)$$

where c_1 is constant for any particular cable.

$$I = \frac{E}{Z_1} = \frac{E}{c_1}\sqrt{n} \quad \ldots\ldots\ldots\ldots (6)$$

Let us assume

$R = 4{,}895$ ohms.
$C = 914.10^{-6}$ farads.
Length $= 2{,}164$ knots

which data represent one of the best transatlantic cables.

Substituting in (5) and (6) we have

$$Z_1 = \frac{923.2}{\sqrt{n}}, \quad \ldots\ldots\ldots\ldots (7)$$

$$I = \frac{E}{923.2}\sqrt{n} \quad \ldots\ldots\ldots\ldots (8)$$

The graph (Fig. 6) represents the impedance-frequency curve at the transmitting end of this particular cable plotted from (7).

For $n = 5$, or at 150 letters per minute, the cable impedance is 412 ohms, or only 8.4 per cent. of the ohmic resistance of the cable.

The impedance of this same cable, as measured by the ammeter-voltmeter method, for a frequency of $n = 5.03$ is 397.5 ohms.

With 50 volts on this cable at the same speed of transmission the current flowing into the cable from (8) is

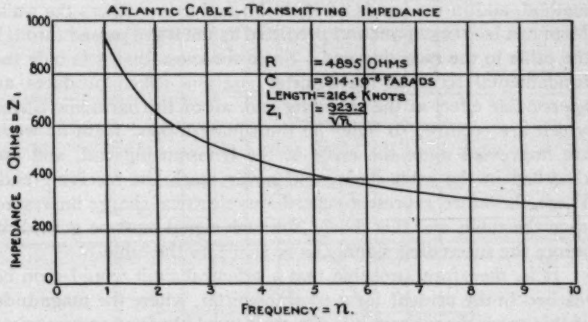
$$I = 0.12 \text{ ampère.}$$

The transmitting impedance is most sensitive to change of frequency at the lower frequencies, and by increasing the speed from $n = 4$, or 120 letters per minute, to $n = 9$, or 270 letters per minute, the cable impedance is decreased in the ratio of 3 to 2, and the current correspondingly increased. The same values of impedance and current deduced above apply to the equivalent

artificial line, which is made to balance as far as possible the real cable.

By inserting a hot-wire ammeter in the cable itself beyond the bridge, and also connecting the transmitting end of the cable to earth, through a suitable voltmeter (preferably an electrostatic instrument, to prevent any disturbance of the bridge balance), we have the means at hand for determining the best transmitting conditions for any particular cable and frequency of signalling. Heretofore the value of the transmitting condensers in the duplex arms of the bridge have been more or less arbitrarily assigned by certain practical rules obtained by an expert study of the signals themselves. Here, however, we may approach the problem more scien-

FIG. 6.



Transmitting impedance of a transatlantic cable as the speed of signalling is varied.

tifically by so adjusting the values of the condensers or inductances, or both, in the bridge branches as to produce a maximum reading of the hot-wire ammeter in the cable itself for any particular voltage assigned. The criterion for best transmitting conditions alone would be that the transmitting impedance should be a minimum, or the current flowing into the cable as measured by a hot-wire ammeter should be a maximum for any particular signalling frequency.

This practical method is, of course, entirely analogous to the present practice of inserting a hot-wire ammeter in the transmitting antenna of a wireless station, except in the latter case we can go much further and adjust for the maximum current possible

at the maximum point of the resonance curve of the antenna. In the cable circuit we are dealing, not with resonance, but with forced waves maintained by the dynamo.

Electrical Stress Upon the Cable.

Submarine cables are at present operated by primary batteries giving an open-circuit voltage of from 50 to 80. The main reason for this is, of course, the constant fear of subjecting the cable itself to undue electrical strain, particularly in the deep-sea portion, where repair is difficult and expensive. This is not the only reason, however, although it is the principal one.

The present form of battery transmitter impresses upon the cable square-topped waves, which may be analyzed by Fourier's method, and in the hands of Malcolm and a few others the wave form can be worked out and predicted as the wave passed through the cable to the receiving end. Since we know that it is only the fundamental term of the Fourier analysis which produces an appreciable effect at the receiving end, all of the harmonic waves which are required to build up the square-topped form of wave are impressed upon the cable at the transmitting end, and are absorbed in the cable itself, and never reach the receiving end. These, therefore, represent superfluous electrical charge impressed upon the cable, and this charge for each signal must be got rid of before the succeeding signal can be sent into the cable.

It is, therefore, probable that a practical limit would soon be reached in the present form of transmitter, where the magnitude of this extra charge sent into the cable would become so great that there would be little advantage in further increasing the E.M.F.

The direct influence which increase of voltage produces on the amplitude of the record received as the frequency changes is shown in the graph (Fig. 7). These data were obtained over a submarine cable from New York City to Canso, Nova Scotia, of

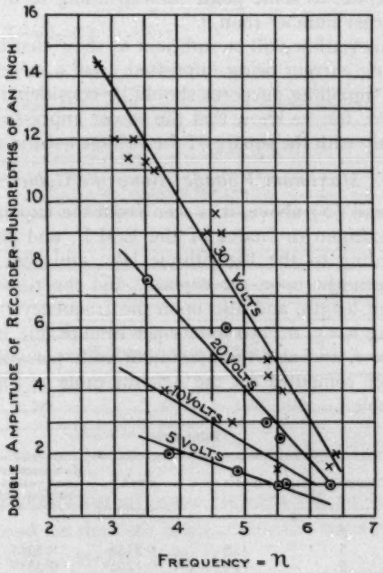
$$R = 13{,}700 \text{ ohms.}$$
$$C = 231.4 \cdot 10^{-6} \text{ farads.}$$
$$\text{Length} = 880.6 \text{ knots.}$$

The cable was used at the transmitting end simplex, without condensers, and at the receiving end the ordinary duplex arrangements were employed with 50 mf. condensers, and the cable recorder was adjusted once for all, and remained unchanged throughout the

experiments. The receiving arrangements were not particularly sensitive, and the recorder was not readjusted as the frequency was increased.

It will be observed that, within the limits of these experiments, the amplitude of the excursions of the siphon increased with the voltage for any particular frequency of the dynamo, and as the frequency was increased, the voltage remaining constant, the

FIG. 7.



Variation of double amplitude of siphon record with change in frequency, voltage constant.

double amplitude of the siphon record gradually decreased. Theoretically, these lines are curved lines, but for observations up to 30 volts, with but one adjustment of the recorder, the right lines in this figure best represent the actual observations at each voltage.

It is seen that these lines converge toward a common vanishing point at somewhere about $n = 7$, which means that, with the

limited sensibility of the particular recorder used (which may be considered as an ammeter if properly calibrated), we cannot expect by any increase of voltage to signal faster than about $n = 7$ with this particular cable.

This graph has been made from data of experiments made 17 years ago, and since that date, due to the great improvement in sensibility of cable relays and amplifiers, the vanishing point at the present day for this cable would be moved to the right along the axis of abscissa, to some point corresponding to n equal a considerably larger number than 7.

The above outline will be sufficient to show that in the case of an alternating current being impressed upon a cable, increase of voltage for signalling purposes should be considered from a new point of view, for we know that the power impressed in this case varies directly with the square of the voltage used in transmitting.

Maximum Voltage Along the Cable.

In (1) and (2) above, it is seen from the exponential factor that the maximum ordinates of the E.M.F. and current waves decay according to the logarithmic law, and that the rate of decay is dependent upon the capacity and the resistance of the cable per unit length, and also upon the frequency.

Assuming $n = 5$, or 150 letters per minute, the instantaneous value of e or i, and also the maximum volts per volt at sending end have been computed for the Atlantic cable of Fig. 6, and are shown in Table I.

TABLE I

Frequency = n	Knots	e or i	Maximum volts per volt at sending end
5	0	1	1
5	135	0·5135	0·5924
5	270	0·1755	0·3510
5	405	0	0·2079
5	540	−0·0616	0·1231
5	675	−0·0630	0·0729
5	810	−0·0432	0·0432
5	945	−0·0222	0·0256
5	1,080	−0·0076	0·0152
5	1,215	0	0·0090
5	1,350	0·0027	0·0053
5	1,485	0·0027	0·0031
5	1,620	0·0019	0·0019

These relations are shown graphically in Fig. 8. It is seen from the table that the maximum voltage impressed upon the cable has decreased to $\frac{1}{1000}$ of its original value in one complete wave-length, and to 0.5924 of the original value in the first 135 knots from the transmitting end of the cable.

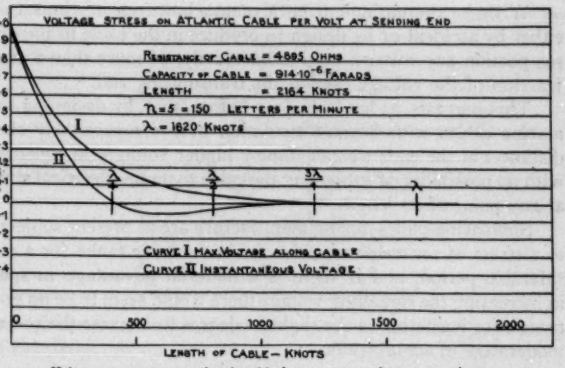
At this speed of signalling a complete wave is 1620 knots in length; also we have

$$\lambda = 1620 \text{ knots}$$

$$T = \frac{1}{n} = \frac{1}{5} \text{ second}$$

Total length of cable $= 1.33\lambda$.

FIG. 8.



Voltage stress on transatlantic cable for n=5, or 150 letters per minute.

Rate of propagation of wave through the cable $= \frac{\lambda}{T} = 8100$ knots per second, or the time required for the wave to travel the length of the cable $= 0.27$ of a second.

The frequency n has a marked influence upon the rate at which the amplitude of the wave decreases as we proceed along the cable from the transmitting end. The distance at which this amplitude will have $\frac{1}{e}$ of its original value is the reciprocal of the coefficient of x in the exponential term of (1), or

$$x' = \sqrt{\frac{2}{CR\omega}} = 258 \text{ knots}$$

or x' varies inversely with the square root of the frequency. This means that if we increase the speed of signalling from $n = 4$ to $n = 9$ the higher frequency wave will experience the same decrease in voltage in two-thirds of the distance from the transmitting end. In other words, the higher the speed of signalling attained on any cable for a given transmitting voltage, the safer the cable is from electrical strain. Increase in efficiency of the cable plant means increase in safety also.

With a battery, it is possible to subject every centimetre of the cable to the full voltage stress of the battery, as occurs whenever the usual insulation resistance test of the cable is made, or in case the transmitting condenser should be accidentally short-circuited.

With the alternating-current dynamo, however, it is impossible either by accident or by design to produce in the cable in the deep sea portion any voltage, even momentarily, of more than a small fraction of the voltage used at the transmitting end.

This suggests, as has been done before, that, by designing submarine cables with heavier insulation over comparatively short distances at the ends we can employ higher voltages in signalling with no possibility of subjecting the cable to undue electrical strain at any point of its length.

Submarine cables during manufacture are at present subjected to a stress of several thousand volts in the cable tanks for a considerable period, and if there is a material advantage in speed in increasing the signalling voltage there would seem to be no good reason for hesitating in the slightest degree to increase the voltage moderately in actual traffic.

Receiving Conditions.

In a long cable there is no reactive influence upon an ammeter or voltmeter placed in any circuit at the transmitting end due to any variation in the form of apparatus inserted at the receiving end of the cable. Opening and closing the cable circuit produces no perceptible indication. The energy of the waves may be considered as leaving the transmitting end of the cable along the conductor path never to return.

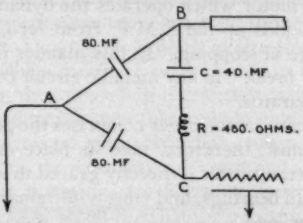
We are, therefore, at liberty to consider the electrical conditions for best receiving, separately and independently of the conditions for sending, and then inquire how far these two sets of conditions can be made to harmonize with each other.

Fig. 9 shows one of the standard arrangements for operating on long cables in which the values of the condensers and the resistance of the recorder coil as shown have become more or less fixed quantities in cable practice. The condenser c is limited to this comparatively small value, as its main function is to improve the definition of letters like "s" and "h," for there is no need to correct for letters like "a" and "n."

This lack of uniform resolving power for all letters at present limits the free use of any value of condenser in this arm which would be the most suitable from electrical considerations to increase the value of an alternating current in the recorder coil.

In Fig. 9 the attenuated alternating current at the receiving end of the cable is divided at the point B of the duplex bridge,

FIG. 9.



Form of duplex circuit used on long cables.

and again subdivided at A and C inversely as the vector impedances of the paths.

In the recorder arm BC the ideal electrical conditions would be to so assign values to the receiving condenser c, and the inductance and resistance of the recorder coil, as to cause this arm of the bridge to be in resonance, entirely independently of the cable itself, the artificial line, or of any other arm of the bridge. In other words, we should so arrange matters if we could that if the arm BC is short-circuited on itself its natural frequency would be equal to the frequency of the current it is required to receive. In the abstract, there would be an infinite number of solutions for this arm, depending upon the stiffness function $\frac{L}{C}$ selected, each solution fulfilling the condition.

$$CL\omega^2 = 1.$$

The Cable Dynamo.

The alternator has been designed for the particular purpose of operating a cable, and possesses some novel features. Since we cannot reduce the number of poles to less than two, we must rely on a high magnetomotive force, and a minimum clearance for the armature to produce, at such low frequencies, the voltage required.

In addition, it is especially desirable to generate an accurate sine wave of E.M.F. These objects have been satisfactorily obtained in the design of the machine used in these experiments.

The resistance of each of the field coils is nearly 1000 ohms, and the inductance of the armature largely controls the current in the armature circuit, so that the machine can be short-circuited at full voltage without harm.

In starting and stopping the dynamo no form of switch is used, but, instead, the motor which operates the dynamo, starting from rest, gradually builds up the E.M.F. from zero, which gradually dies down to zero at stopping. In this manner there is never any possibility of a "break" in any metallic circuit connected with the transmitting apparatus.

Since the dynamo transmitter comprises the power plant for an ocean cable, it must, therefore, take its place on the instrument table, where the transmitter is directly geared to it. The armature is mounted on ball bearings, and runs with remarkable silence and smoothness under load.

The developments of wireless telegraphy have introduced alternating-current dynamos of considerable power of 100,000 and even 200,000 cycles per second; but for the present purpose we require an alternator to operate at from 4 to 10 cycles per second, and to develop 100 volts or more. This type of dynamo possesses some interest to the engineer, because it may be said to represent the extreme infra-red end of the dynamo spectrum, just as the high-frequency machines mentioned above represent the ultra-violet end. It would be strange indeed if the needs of telegraphy should be ultimately responsible for the development of both ends of this spectrum.

IV. *Summary.*

In the phenomenal development of the wireless art many instruments and methods have been imported from the much older art of wire telegraphy. In like manner may we not, to advantage,

re-import some of the methods and instruments developed in wireless telegraphy into the art and science of cable telegraphy?

It has been truly said that "we begin to understand a phenomenon when we can measure it," and for this reason alone the present plan, it is thought, will appeal to physicists and engineers.

It is seen that once we can employ a system of signalling in which we are dealing with one fundamental frequency only, and the circuit is never broken, the process of measuring the constants of the cable itself and the most suitable bridge arrangements for high efficiency is greatly simplified.

The removal of any form of arc or spark from the cable circuit has been shown to very materially increase the accuracy of balancing the duplex bridge, while the smooth type of waves employed in sending the signals has enabled this important object to be attained with an accuracy greater than has been possible before.

Using the low-resistance coil of a transformer or autotransformer as the actual source of E.M.F. in the circuit comprising the cable itself enables each end of the cable to be permanently connected to earth, thus providing a drainage path for earth currents of all kinds induced in the cable, and also adding to its safety.

The present forms of cable recorders, relays and amplifiers, when relieved from the necessity of recording consecutive impulses in the same direction, are liberated from some practical restrictions which have heretofore hampered them.

In the example shown the recorder coil of the gold-wire relay oscillates back and forth at a definite frequency, and the inertia of the moving parts is, therefore, less troublesome, and we are at liberty to increase the flux of the magnetic field as well as reduce the control of the coil so as to allow it to vibrate more freely at its natural frequency.

No mention has been made of the possible application of this method of transmission to landlines, but it may be remarked that in the present Wheatstone automatic system there is great trouble caused by the induction of one line upon another, and if we could remove from the Wheatstone system the necessity of making and breaking the battery circuit at comparatively high voltage we could, at a single stroke, very largely reduce all such inductive effects.

The more usual method of developing a system of telegraphy is what might be called the "synthetical method"—that is, having

certain fundamental principles which are proved to be correct, to endeavor to build up a system in practice which will possess as many as possible of these principles.

This method was employed in the earlier stages of these experiments, but it was only after abandoning this course altogether, and starting with the ideal solution as outlined above, that it was possible to proceed without radical compromise. It is known, for instance, that certain characteristics are very desirable in any cable system, such as

(*a*) All signals should represent equal lengths of time;

(*b*) No two consecutive signals should be of the same sign;

(*c*) The resolving power or definition of each letter of the alphabet should be as nearly as possible the same;

(*d*) The total quantity of electricity measured in coulombs impressed upon the cable should be as nearly as possible equal to zero for any two consecutive signals.

It will be seen, however, that the ideal solution for power transmission automatically comprises each of these conditions, and, in addition, has other advantages in safety to the cable property from undue electrical strain throughout every centimetre of its length.

The Vapor Pressure of Ethane and Ethylene at Temperatures Below Their Normal Boiling-points. G. A. BURRELL and I. W. ROBERTSON. (*The Journal of the American Chemical Society,* vol. xxxvii, No. 8, August, 1915.)—The authors of this report have needed at various times in working on the condensation of the constituents in natural gas and in studying the separation of gas mixtures by fractionally distilling them certain vapor-pressure measurements of gases at low temperatures. These have not been determined in the case of ethylene and only for a limited range (20° below the normal boiling-point) in the case of ethane. Hence in this paper are shown observations from 760 mm. down to 1 mm. Vapor pressures of propane, propylene, N-butane, iso-butane, butylene, and acetylene will follow in subsequent articles.

Saturated vapor pressures for ethane and ethylene at low temperatures are shown. In the case of ethane, the vapor pressures range from 760 mm. at −89.3° to 1 mm. at −159.8°. In the case of ethylene, the vapor pressures range from 760 mm. at − 103.9° to 4 mm. at −159.9°.

The authors' experience with a bath devised by Henning for maintaining a constant low temperature is described.

THE PHYSICAL PHOTOMETER IN THEORY AND PRACTICE.*

BY

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I.

It is well known that the photometry of light sources which are different in color is subject to great errors. In order to obviate this difficulty some form of radiometer which, unlike the eye, functions independently of the frequency (wave-length) and the intensity of the stimulus, has been advocated.

A bolometer or a thermopile is the simplest radiometer now available. In order to make it conform with the behavior of the average normal eye when subjected to a stimulus which does not deviate much from a certain specified intensity, it is necessary to interpose between the radiometer and the source of light (which is to be tested) an absorption screen which is opaque to all the infra-red and ultraviolet radiations and which transmits the visible radiations in proportion to the luminosity curve of the average normal eye. In other words, the spectral transmission curve of the absorbing medium must be an exact copy of the luminosity curve of the average normal eye, when subjected to a stimulus of a given intensity.

All this sounds very enticing in theory, but in practice the radiometer has various limitations which, as will be shown presently, may restrict its use to special problems which can be investigated at leisure, when conditions are favorable for operating the radiometric outfit.

This paper makes no pretence in giving the details of the development of the aforementioned ideas. In the earliest work by Féry [1] an absorption cell containing a solution of copper acetate was used, and no attempt was made to have its transmission curve coincide with the luminosity curve. Recently Karrer [2] has made a series of radiant luminous efficiency measurements on various light sources by determining the ratio of energy

* Communicated by the Author.

[1] Féry, *Bull. Soc. Franç. Physique*, p. 148, 1908.

[2] Karrer, *Physical Review*, 5, p. 189, 1915.

transmitted by the luminosity curve solution to the total energy radiated. The solution used by Karrer has been modified, and the one now recommended[3] has the following composition:

Cupric chloride	60.0 gr.
Potassium chromate	1.7 gr.
Cobalt ammonium sulphate	7.5 gr.
Nitric acid, sp. gr. 1.05	15.0 Cc.

Water to one litre of solution.

This solution is to be used in a parallel-walled glass tank 1 centimetre in thickness, but, as will be shown presently, this is not a sufficient thickness to be entirely opaque to infra radiations.[4] Fortunately the solutions used by Karrer were in separate tanks, forming a total thickness of 4.2 cm., which, as will be shown on a subsequent page, is sufficient to eliminate all the infra-red.

The question of the mechanical valuation of visible radiation, "light," by using a radiometer and an absorbing screen whose transmission curve coincides with the luminosity curve of the eye has been discussed by Houstoun,[5] Ives and others. Ives[6] has recently discussed the subject of physical photometry, and in his instrument the visual luminosity medium is complete in one solution. Unfortunately no mention is made of the thickness of the cell, which, from the printed illustration, appears to be 1 cm. in thickness.

The present inquiry into the merits of the physical photometer came about quite accidentally in connection with the question of the photometric determination of the transmission of a yellow and a blue solution for the luminous radiations from a "4-watt" carbon lamp. The yellow solution consists of 72 grammes of potassium dichromate per litre, and the blue solution contains 53 grammes of copper sulphate per litre; these being the concentrations specified by Ives and Kingsbury[7] to give the same

[3] Ives, Coblentz, Kingsbury, *Phys. Review* 5, p. 269, 1915.

[4] The concentration of cupric chloride in the aforementioned luminosity solution amounts to only about 3 per cent. for a 2 cm. thickness. (Beers's law. Thickness and concentration are interchangeable.) In a previous paper (*Bull. Bur. Standards*, 9, p. 110, 1912) I have shown that a 3 per cent. solution is not sufficient to absorb all of the infra-red spectrum.

[5] Houstoun, *Proc. Roy. Soc. A*, p. 275, 1911.

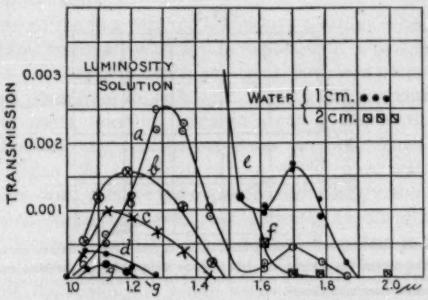
[6] Ives, *Trans. Illum. Eng. Soc.*, 10, p. 101, 1915.

[7] Ives and Kingsbury, *Trans. Illum. Eng. Soc.*, 10, p. 203, 1915.

transmission (for the light from a "4-watt" carbon lamp) as determined with a "physical photometer" (to be described shortly), which presumably employed the aforementioned luminosity solution.

The copper sulphate solution is opaque to radiations beyond 0.9μ, and the dichromate solution is opaque beyond 1.4μ. Consequently the copper sulphate solution will absorb most of the radiations transmitted (at 1.2μ) by the luminosity curve solution; but they will not be absorbed by the dichromate solution. Hence, in making up a copper sulphate solution to give the same radiometric transmission as that given by the dichromate solution, the sulphate solution is to be expected to be the more transparent

FIG. 1.



Showing the region of transparency in the spectrum of the luminosity curve solution.

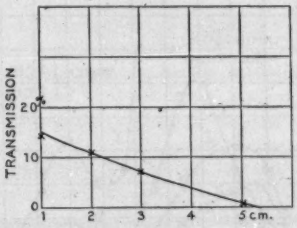
when measured radiometrically by means of a physical photometer employing a luminosity curve solution which is (as it should be) entirely opaque to infra-red radiations.

In order to determine the validity of this surmise, the spectral transmission of these various solutions was determined by means of a fluorite prism and the spectro-radiometric apparatus used in various researches previously published. The galvanometer was steady to 0.1 mm. The Nernst glower used gave from 200 to 300 cm. deflection, so that it was an easy matter to make observations to 2 parts in 30,000 in the spectral region of 1μ to 2μ. The luminosity curve solution was found more transparent (Fig. 1, curve *a*) than anticipated, for a 1-cm. layer, and the greatest surprise was the observation of an additional transparent region

at 1.7μ. This band is found in pure water (*i.e.*, it is not caused by the coloring matter in solution), and is not entirely eliminated in a 1-cm. layer. This is shown more clearly in an examination of pure water, curves *e* and *f*, Fig. 1, where this transparent region is entirely eliminated (curve *f*) in the 2-cm. layer of water.

The depression in the left-hand side of curve *a*, Fig. 1, was verified on a subsequent examination, from which it would appear that Beers's law (which states that the thickness and concentration are interchangeable) may not hold for highly-concentrated solutions. Curve *a* is entirely different from the transmission curves of cupric chloride previously published. Curve *b*, which gives the transmission of the luminosity solution diluted

FIG. 2.



Showing the percentage of infra-red radiations as compared with the luminous radiations from a "4-watt" carbon lamp which are transmitted by a layer of luminosity curve radiation, 1, 2, 3, etc., centimetres in thickness.

one-half and examined in a 2-cm. layer (hence equivalent to a 3 per cent. solution), agrees exactly with the data of a 3 per cent. solution of cupric chloride previously published.[8] Curves *c* and *d*, Fig. 1, give the transmissions of the above-mentioned luminosity solution diluted to one-third and one-fifth of its concentration, and examined in layers 3 and 5 cm., respectively, in thickness. This was done in order to determine what thickness of water (solution) would be necessary to eliminate the transparent band at 1.2μ in the luminosity curve solution. This could be accomplished by using a greater concentration of cupric chloride, but this would necessitate working out a new luminosity curve solution. Using a cell 5 cm. in thickness, and a concentration of

[8] Coblentz, *Bull. Bur. Standards*, 9, p. 110, 1912.

one-fifth of the prescribed ingredients of the above-mentioned luminosity curve solution, the amount of infra-red is from 0.6 to 0.8 per cent. of the visible radiations transmitted from a "4-watt" lamp. However, before using this solution it will be necessary to determine first whether the transmission curve has been appreciably modified, in the visible spectrum, by diluting the standard solution to one-fifth and then using it in a 5-cm. layer, instead of 1 cm. as prescribed.

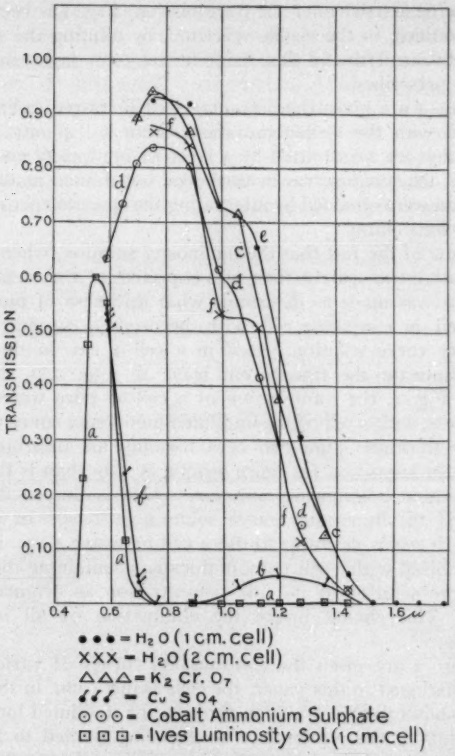
In Fig. 2 are given the percentages of infra-red radiations as compared with the visible radiations from a "4-watt" carbon lamp, which are transmitted by a layer of luminosity curve solution, 1, 2, etc., centimetres in thickness, but diluted as described. These data were obtained by integrating the spectral energy curves of a "4-watt" lamp.

In view of the fact that the luminosity solution, when diluted, became more transparent than was expected, at 1 to 1.2μ, an examination was made to determine what thickness of pure water when used, in a separate cell, with the original concentration of luminosity curve solution (used in a cell 1 cm. in thickness), would eliminate the transparent band at 1.3μ. As shown in curve *g*, Fig. 1, the combination of a cell of pure water, 3 cm. in thickness, with a cell of the undiluted luminosity curve solution, 1 cm. in thickness (the two cells forming an absorbing layer 4 cm. in thickness), is far more opaque at 1.2μ than is the 5-cm. layer of diluted luminosity solution. This is due to the great opacity of the luminosity curve solution at 1.1μ. In practice, however, it seems desirable to use a cell of water 4 cm. in thickness, combined with a cell 1 cm. in thickness containing the luminosity curve solution in its full concentration as originally prescribed. This should insure the elimination of all infra-red radiations.

In Fig. 3 are given the transmission curves of various substances discussed in this paper, the cells being 1 cm. in thickness. Curve *a* shows the transmission through the undiluted luminosity curve solution, the region at 1 to 2μ being plotted to a larger scale in Fig. 1. Curve *b* gives the transmission of copper sulphate (53 grammes per litre); and curve *c* gives the transmission of potassium dichromate (72 grammes per litre) mentioned on a previous page. The transmission of cobalt ammonium sulphate (6 gr. in 94 Cc. of water; 6 per cent. solution) is given in

curve *d*. Curves *e* and *f* give the transmissions of pure water in layers 1 and 2 cm., respectively, in thickness. It is to be noted that the potassium dichromate and the cobalt ammonium sulphate

FIG. 3.



Transmission of various solutions.

solutions are almost as transparent as pure water, in marked contrast with the solutions of copper salts.

The numerical values of the transmissions of the various solutions and of pure water are given in Table I.

TABLE I

Transmission of Various Solutions.

Wave-length	Luminosity curve solution					Water		Copper sulphate	Potassium dichromate	Cobalt ammonium sulphate
μ =0.001 mm.	Undiluted. Cell 1 cm.	Diluted to $\frac{1}{2}$. Cell 2 cm.	Diluted to $\frac{1}{3}$. Cell 3 cm.	Diluted to $\frac{1}{5}$. Cell 5 cm.	Cell 1 cm. + Water Cell 3 cm.	Cell 1 cm.	Cell 2 cm.	Cell 1 cm.	Cell 1 cm.	Cell 1 cm.
.882μ	.....	.....	.....	.....	.....	.912	.842	.0016	.871	.802
.991	.00000	.00000	.....	.00010	.....	.731	.530	.....	.....	.615
1.054	.00026	.00045	.00045	.00044	.00015	.....	.....	.031	.715	.....
1.123	.00058	.00115	.00105	.00043	.00022	.656	.507	.....	.....	.415
1.197	.0012	.00157	.00085	.00022	.00015	.....	.....	.050	.376	.....
1.276	.0023	.....	.00074	.00014	.00006	.308	.113	.....	.....	.147
1.357	.0021	.00105	.00036	.00006	.00001	.....	.....	.031	.124	.....
1.441	.00092	.00015	.00008	.00000	.....	.0525	.0259	.....	.....	.0225
1.526	.....	.00003	.00000	.....	.....	.00123	.....	.....	.....	.....
1.613	.00019	.00000	.....	.....	.00000	.00098	.00005	.0005	.0013	.00074
1.698	.00047	.00004	.....	.....	.00000	.00170	.00000	.0008	.0020	.00101
1.784	.00027	.00000	.....	.....	.....	.00113	.00000	.0005	.0013	.00082
1.869	.00000	.....	.....	.....	.....	.00024	.....	.....	.....	.....

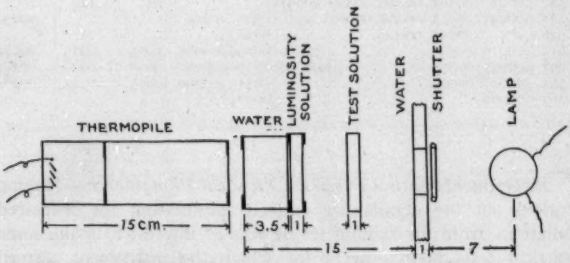
II.

Experiments with a Precision Physical Photometer.—Having worked out the details for entirely eliminating the infra-red radiations from the radiometer, it was of interest to make some practical tests upon objects for which the instrument seemed adapted. Because of the lack of sensitivity of the radiometer, as compared with the eye, this device cannot measure very small variations in luminous intensity, unless a very sensitive galvanometer can be employed. However, for standardizing colored solutions which are to be used as transmission screens in physiological, psychological, and photometrical investigations, the physical photometer appears to have an important field. Further investigation of the instrument will, of course, be necessary, especially the luminosity curve solution, the temperature coefficient of transmission of which must be determined.

The physical photometer, as used in the present work, is a very simple device, consisting of a surface (or linear) thermopile of bismuth-silver, at a short distance of about 15 cm. in front of which was placed the luminosity curve solution and water cell. The lamp stood at a distance of about 20 cm. from the water cell, and in the intervening space stood a water-cooled diaphragm and

shutter, as shown in Fig. 4. The bismuth-silver thermopiles used have been described elsewhere.[9] The design and behavior of the surface thermopile used in this work have been described recently.[10] The auxiliary galvanometer used is the newly-designed ironclad instrument [11] in which the magnetic perturbations have been eliminated. This is more important than the question of sensitivity, which in the present work was $i = 5 \times 10^{-10}$ ampère for a single swing of 2 seconds. In view of the fact that the luminosity curve solution becomes warmed by absorbing most of the radiations from the lamp, and causes a drift of the galvanometer reading by radiating upon the thermopile, the ballistic

FIG. 4.



Showing the arrangement of the physical photometer.

throw of the galvanometer was used. This throw is known to be proportional to the final steady deflection, and could be measured in 2 seconds. It was therefore possible to make a radiometric measurement in 5 to 6 seconds.

The Transmission of Solutions.—The first tests were made on the "blue" (copper sulphate) and the "yellow" (potassium dichromate) solutions mentioned on a previous page, and, in view of the fact that it is desirable to illustrate the precision attained, the data are given *in extenso*. The first trial was with linear thermopile No. 53 and a cell 1 cm. in thickness, containing the luminosity curve solution at 28° C. The source was a "4-watt" carbon lamp. As already stated, the 1-cm. solution

[9] This JOURNAL, 172, p. 559, 1911; *Bull. Bur. Standards*, 11, p. 132, 1914.
[10] *Phys. Rev.* (2), 5, p. 269, 1915.
[11] *Bull. Bur. Standards*, 9, p. 61, 1912; 11, p. 180, 1914.

transmits 13.6 per cent. of the infra-red radiations from the "4-watt" lamp. Of the 13.6 per cent. infra-red transmitted by the luminosity curve solution, 19.5 per cent. is transmitted by the yellow solution and 3.7 per cent. is transmitted by the blue solution. In both cases erroneous results must occur in attempting to determine their transmission for luminous radiations, when using the 1-cm. cell of luminosity solution. This fact is demonstrated by taking the ratios of the transmissions $\frac{\text{blue}}{\text{yellow}}$. A series of seven measurements (July 26, ratio $B:Y = 1.021$, 036, 020, 032, 031, 013, 027) gave a mean value of $B:Y = 1.026$. Repeating the work with a surface thermopile (July 30, $B:Y =$ 1.018, 020) gave a mean value of $B:Y = 1.019$.

A layer of water 1 cm. in thickness, used in addition to the 1 cm. luminosity solution, removes part of the infra-red transmitted by this solution, and thus reduces the amount transmitted by the yellow (and blue) solutions. The ratio of $B:Y$ should therefore be larger than the one just determined. A series of six measurement (July 26, linear thermopile, ratios $B:V = 1.055$, 040, 048, 030, 042, 044) gave a mean value of $B:Y = 1.043$, which larger value was to be expected.

Using only the 1-cm. cell of luminosity solution, the transmission of the yellow solution was 0.547. Correcting this value by 13.6 per cent. for the infra-red which is transmitted by the luminosity solution, the true transmission (at 29° C.) of the yellow solution, for the *visual* radiations from a "4-watt" carbon lamp, is 0.622, which, as will be noticed presently, is in remarkably close agreement with the value obtained by using a luminosity solution which transmits no infra-red radiations. This close agreement is to be emphasized because the correction factor of 13.6 per cent, was obtained (by integrating the part of the spectral energy curve of the "4-watt" lamp) before the luminosity curve solution and water-cell combination, for eliminating all the infra-red, had been developed.

The crucial test of these transmissions was made with a surface thermopile No. 46, and the combination of a 1-cm. cell of luminosity curve solution and 3.5 centimetres of water. The water happened to be in two cells, 1 and 2.5 cm., respectively, in thickness, the luminosity solution cell being between them. Black paper diaphragms, with holes smaller than the inside diameter

of the glass walls of the cells, prevented reflections. To prevent reflections from the intervening glass windows, in one series of measurements ("August 4," to be mentioned presently) these cells were joined with glycerine. However, there is no difference in the results. A series of ten measurements (August 3, temperature 29°, ratio $B:Y=1.085, 085, 095, 080, 079$; August 4, $B:Y=1.083, 079, 083, 077, 082$) gave a mean value of $B:Y=1.083$. In other words, the blue solution transmits over 8 per cent. more visible radiations ("light") from the "4-watt" carbon lamp than does the yellow solution. As stated in the beginning of this paper, if blue and yellow solutions are made up to give equal transmissions, for a "4-watt" lamp, as determined radiometrically, using only the 1-cm. layer of luminosity solution which transmits 13.6 per cent. of the infra-red radiations of this lamp, then the blue solution must be the more transparent when tested with a luminosity curve solution which transmits no infra-red radiations.

The transmission of these solutions for the visible radiation from a "4-watt" lamp was determined radiometrically, using the aforementioned combination of 1 cm. of luminosity curve solution and 3.5 cm. of water, which eliminates all of the infra-red. A series of nine measurements (August 3, 0.623, 0.629, 0.620, 0.616; August 4, 0.620, 0.617, 0.623, 0.624, 0.622) gave a mean value of 0.621 for the transmission of the yellow solution; and from this, using the ratio of $B:Y=1.083$, the transmission of the blue solution is 0.673. In other words, the yellow solution transmits 62.1 per cent. and the blue solution transmits 67.3 per cent. of the "light"—the visible radiations from a "4-watt" carbon lamp. These two solutions, in their cells, were loaned to me by my colleagues, Messrs. Crittenden and Richtmyer, who are investigating them photometrically. It will therefore be of interest to await their results. As already mentioned, it will be necessary to determine the temperature coefficient of transmission for the different wave-lengths transmitted by the luminosity curve solution. Unless the unusually close agreement between the photometric and radiometric measurements on a standard lamp, to be described presently, are merely fortuitous, it would appear that the temperature coefficient is of minor importance.

Determinations of transmission of the yelow solution and of the ratio blue to yellow were made with the luminosity solution

diluted to one-fifth and used in a 5-cm. cell. The mean value of 12 closely agreeing determinations of the transmission of the yellow solution was 0.624, which is in agreement with the above-mentioned measurements, viz., 0.621. There is one inconsistency in that the ratio of the blue to yellow is 1.001. This can be explained if the whole absorption band of the luminosity solution is shifted toward the visible spectrum, which would affect the blue solution. In view of the fact that the 5-centimetre cell of diluted luminosity curve solution is not perfectly opaque in the infra-red, and hence not perfectly satisfactory, it seemed unnecessary to pursue the investigation. As a question affecting "Beers's law" of the interchangeability of thickness and concentration of solution, it would be of interest to investigate the effect of change in concentration upon the transmission band of the luminosity curve solution.

Measurements on a Standard Incandescent Lamp.—In the foregoing tests all the measurements were made by one observer and his assistant. To eliminate all possible bias in the final results, and to make a thoroughly practical test of the physical photometer, measurements were on a vacuum tungsten lamp, kindly supplied by my colleagues, Messrs. Middlekauff and Skogland. This is one of a series of lamps, photometered by a group of observers, and the constants are accurately determined. The only data supplied me at the start were the currents on which the lamp was to be operated (see Table III).

In these radiometric measurements the combination of luminosity curve solution and 3.5 cells of water was used as already described. The currents were regulated by measuring the potential across a standard 1-ohm resistance, by means of a potentiometer. It was found that a change of 1 per cent. in the current changed the galvanometer (sensitivity $i = 5 \times 10^{-10}$ ampère) deflection 6 to 8 mm., so that a change of 0.1 per cent. in current made an appreciable change in the deflections, which usually could be read to 0.1 to 0.2 mm. The assistant therefore kept the current constant to 0.0001 ampère, and recorded the observations.

After changing the current in the lamp, it was often necessary to keep the shutter raised several minutes in order to establish temperature equilibrium between thermopile and the absorption cells before making observations.

Another difficulty encountered was that the operating cur-

rents through the lamp differed too much in magnitude, so that in taking ratios the galvanometer deflections differed considerably. The galvanometer being undamped on a 2-second swing, was not well adapted for this test. The ballistic throw is not proportional for very large deflections (12 to 15 cm.) as compared with small deflections, being too large when observing large deflections. This makes the ratios larger than the true value. This, of course, was known before making the observation, and such readings should therefore not have been included in determining the mean value. In Table II are given the ratios of the luminous intensities of the lamp for the different currents (say 0.3258 and 0.3108 ampère), the spacing of the horizontal lines indicating the order of observations. The value 1.356 is too high because of the large ballistic throw. The values 1.373 and 1.332 are poor sets, due to a sudden unsteadiness ("kicks") in the galvanometer, which occurs unexpectedly, at infrequent intervals, and which is supposed to be caused by radiotelegraphic disturbances.

TABLE II

Giving the Ratios of Luminous Intensities, as Determined with a Physical Photometer, for Different Currents (see Table III).

Ampères		
·3258 ·3108	·3404 ·3258	·3542 ·3404
1.356 →	1.319	
	1.311	
←	1.311	
1.351		
1.344		
1.346 →	1.313	
	1.314	
	1.313 →	1.273
		1.280
		1.273
	←	1.274
1.373 }	Poor set.	
1.332 }		
1.337		
Mean values		
1.347	1.313	1.275

These ratios were tabulated and the results handed to Dr. Middlekauff, who then gave me the complete data recorded in Table III. The ratios of the luminous intensities (candle-powers) and the ratios of the intensities determined radiometrically are

in surprisingly close agreement, especially when one considers that the radiometric measurements were made in three hours, while the photometric measurements involve many observers and weeks of intercomparison. In a total change of luminous intensity amounting to over 23 candle-power, the difference between the photometric and the radiometric determination is less than 0.2 per cent.

TABLE III

Showing the Constants of a Vacuum Tungsten Lamp, Determined Photometrically; and Radiometrically Using a Physical Photometer. In a Total Range of Luminous Intensity Amounting to 23 c.p. the Difference between the Photometric and the Radiometric Determination is only 0.2 per cent.

Volts	Ampères	Candle-power	Watts per candle	Ratio of candle-power (column 3)	Ratio of intensities determined with a physical photometer
96	.3108	18.21	1.628		
104	.3258	24.50	1.375	1.345	1.347
112	.3404	32.28	1.174	1.316	1.313
120	.3542	41.03	1.030	1.271	7.275
			Ratio: 41.03÷18.21=2.252		2.256

The advantage of such a device as the physical photometer for measurements in heterochromatic photometry is apparent. One can compare lamps with the standards, regardless of color. However, the problem is not entirely solved, for further information must be obtained on the luminosity curve solution, as well as on the luminosity curve of the so-called average eye.

Summary.—This paper gives data showing that a given luminosity curve solution transmits 13.6 per cent. infra-red radiations from a "4-watt" carbon lamp, due to the fact that this solution has a region of considerable transparency at 1.0 to 1.3μ. Experiments are given showing that the concentration and the thickness of this solution are not interchangeable—at least not for the infra-red region at 1.2μ. In order, therefore, to eliminate all the infra-red, by means of water, it is therefore necessary to use the luminosity curve solution and the water in separate cells. A layer of water 4 cm. in thickness is recommended, to be used with the 1-cm. layer of luminosity curve solution, in order to entirely absorb the infra-red spectrum.

A precision physical photometer is described, consisting of a thermopile in front of which is placed the above-mentioned combination of luminosity curve solution and water cell. Practical

tests are made with this instrument, including the measurement of the transmission of certain yellow and blue solutions for the visible radiations from a "4-watt" carbon lamp. Precise measurements were made on ratios of luminous intensities of a standardized vacuum tungsten lamp, and the radiometric measurements were found in agreement within 0.2 per cent. with the photometric measurements.

In addition to the gentlemen mentioned in the text, especial acknowledgment is due my assistant, Mr. W. B. Emerson, for assisting in this work.

WASHINGTON, D. C., August 6, 1915.

Since writing the above paper, Dr. Ives has called my attention to his latest recommendations (in the *Trans. Illum. Eng. Soc.*, 10, p. 315, 1915) relative to the use of the physical photometer.

The luminosity curve solution given above has been modified, so that its transmission curve more nearly approximates the color sensibility curve of the average eye.

The concentrations now recommended are:

Cupric chloride	60.0 grammes
Potassium chromate	1.9 grammes
Cobalt ammonium sulphate	14.5 grammes
Nitric acid (1.05 gr.)	18.0 c.c.
Water to	1 litre

This solution, which is to be used in a cell 1 centimetre in thickness, is to be protected from overheating by the interposition of a layer of clear water at least 2 cm. in thickness.

As mentioned in the text, a cell of clear water not less than 4 cm. in thickness is necessary in order to render this absorption screen entirely opaque to all the infra-red.

In conclusion, it is desirable to call attention to the fact that the data on the "Mechanical Equivalent of Light" (Ives, Coblentz and Kingsbury), *Phys. Rev.*, 5, p. 269, 1915) which relate to the measurements with the luminosity solution and the "4-watt" lamp must be corrected by 13.6 per cent., because of infra-red transmitted by the luminosity curve solution. In a forthcoming paper by the writer on the coefficient of total radiation of a black body, data will be given which place the value of this constant at $\sigma = 5.74 \times 10^{-12}$ watts per cm.^{2} per deg.^{4} This is the same as the value (5.7×10^{-5}) used in calibrating the lamp standards employed in the above measurement of the mechanical equivalent of light. There is therefore no correction to the lamp standard used in calibrating the thermopile, excepting a possible correction of perhaps 1 or 2 per cent. for atmospheric absorption by water vapor. This, however, is a greater refinement than the original data admit. The investigation of the mechanical equivalent of light must, of course, be undertaken anew, in view of the experience gained and the improved facilities now available.

AUGUST 9, 1915. W. W. C.

ON THE FACTOR TO BE USED FOR THE CALCULATION OF THE PHOSPHORIC ACID IN NEUMANN'S METHOD.
THE FACTOR AS INFLUENCED BY THE WATER USED FOR WASHING THE YELLOW PRECIPITATE.[1]

BY

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INTRODUCTION.

In our investigation into the chestnut bark disease caused by a fungus parasite known as *Endothia parasitica*, and more especially in our study of the metabolism of the chestnut bark under physiological and pathological conditions, it was deemed advisable, among other things, to ascertain the phosphorus content of healthy and infected chestnut bark. A preliminary examination showed both of them to contain but a small proportion of phosphorus. This suggested the use of an accurate method which, because of the considerable number of bark samples to be analyzed, had also to be expeditious. Owing to the important rôle the phosphoric acid plays both in the organic and inorganic world, many methods, gravimetric, volumetric,[2] acidimetric,[3] iodometric,[4] colorimetric,[5] have been devised for its estimation. While the gravimetric[6]

[1] Read at the meeting of the American Chemical Society, New Orleans, March 31 to April 3, 1915, and published by permission of the U. S. Secretary of Agriculture.

[2] *Z. anal. Chem.*, **9**, 203 (1870); *Bull. soc. chim.*, **50**, 353 (1888); *Compt. rend.*, **93**, 495 (1881); *Jahresber. Chem.*, Liebig u. Kopp, **1853**, 642; *Arch. wiss. Heilk.*, **4**, 228; *J. prakt. Chem.*, **76**, 104 (1859).

[3] Hundeshagen, *Z. anal. Chem.*, **28**, 171 (1889); Thilo, *Chemiker Z.*, **11**, 193 (1887); Manby, *J. Anal. Appl. Chem.*, **6**, 82 (1892); Handy, *Ibid.*, **6**, 204 (1892); Pemberton, *Jour. Amer. Chem. Soc.*, **15**, 382 (1893).

[4] *Z. anal. Chem.*, **20**, 507 (1881); *Ber.*, **28**, 2061 (1895); *Z. anal. Chem.*, **36**, 81 (1897); *Z. landw. Versuchsw.*, **17**, 92 (1914).

[5] *Bull. soc. chim. Paris*, **47**, 745 (1887); *Pharm. Centralbl.*, **35**, 170 (1894); *Chem. Centralbl.*, **68**, 126 (1897); *Jour. Amer. Chem. Soc.*, **23**, 96 (1901); **25**, 169 (1903); **25**, 1056 (1903); **26**, 808 (1904); **26**, 1463 (1904); **27**, 121 (1905).

[6] Fresenius, "Quant. Analys.," 6th edition, vol. i, 402 (1903); Treadwell, "Analyt. Chemistry," 3d edition, vol. ii, p. 434 (1914).

methods are undoubtedly the most accurate known, they have the disadvantage in that they require for their execution more time and larger quantities of material than the volumetric methods do.

Of the considerable number of acidimetric methods described, many of which are based on the titration of the ammonium phospho-molybdate precipitate, the one presented by Neumann [7] seems to be quite generally in vogue. Not only is Neumann's method preferably employed in biological investigations for the determination of phosphoric acid in nucleic acids, lecithins, phosphatides, animal and plant tissues, etc., but in ores, steel, iron, phosphate rocks, and fertilizers just as well.

The Incorrectness of the Factor Employed in Neumann's Acidimetric Method.

Despite the fact that Neumann's method has been in use already for over ten years, it was only very recently that Heubner [8] and Wardlaw [9] have shown the factor 0.554—as proposed by Neumann and applied in his method for the calculation of phosphoric acid—to be incorrect. The experimental evidence presented by Heubner demonstrated that the above-mentioned factor, leading as it does to the not negligible error of about three per cent., is to be replaced by the factor 0.57, which is more nearly correct. From this it would seem that previous records in the literature of phosphoric acid estimations according to Neumann's method must have been too low. The latter method being of great practical value as well as of general interest, a solution of the question as to which of the two factors—Neumann's or Heubner's—is correct seemed to be desirable, if not imperative. Moreover, additional data, it was hoped, might help to clear up the discrepancy between the factor theoretically deduced by Neumann and the factor empirically secured by Heubner. Furthermore, this question had a specific interest for us, inasmuch as we had applied Neumann's acidimetric method to our work on the chestnut bark disease prior to the publication of Heubner on the factor to be applied in Neumann's method.

[7] A. Neumann, *Z. physiol. Chem.*, **37**, 129 (1902–03); **43**, 35 (1904–05); Gregersen, *Z. physiol. Chem.*, **53**, 453 (1907); Bang, *Bioch. Z.*, **32**, 443 (1911).

[8] *Biochem. Z.*, **64**, 393 (1914).

[9] *Chemical Abstracts*, **8**, 3540 (1914).

The Theory of Neumann's Method.

Neumann based his method on the fact that the yellow precipitate of ammonium phosphomolybdate obtained from a nitric acid solution under certain conditions has—as was demonstrated by the work of Hundeshagen[10]—the composition: 12 MoO_3, $(NH_4)_3PO_4$, 2 HNO_3. Taking into consideration that a sharp and exact titration of the yellow precipitate against standard alkali, with phenolphthalein as indicator, can be accomplished only after the ammonia has been removed, we obtain, on doubling the above formula, the following equation: 24 MoO_3, 2 $(NH_4)_3PO_4$, 4 HNO_3 + 56 NaOH = 24 Na_2MoO_4 + 2 Na_2HPO_4 + 4 $NaNO_3$ + 32 H_2O + (6 NH_3). This means that 56 molecules of NaOH required to neutralize the yellow precipitate and to remove the ammonia correspond to 2 Na_2HP_4 (= 142 grs. P_2O_5). By using $\frac{n}{2}$ NaOH for titration we can express the above data as follows: 112 litres of $\frac{n}{2}$ NaOH = 142 grs. P_2O_5, hence 1 c.c. $\frac{n}{2}$ NaOH is equivalent to 0.554 milligramme P. It is this factor (0.554) that proved to be about three per cent. lower than the average factor (0.57) to which the work of Heubner has led.

Heubner's factor having been fully corroborated by the work of one[11] of us, as giving very nearly correct results under the conditions outlined in the paper, the question seemed of considerable interest as to what causes the deviation from the theoretical factor 0.554. Several reasons may be responsible for this difference. In the first place it has been stated in the literature by various investigators that the composition of the yellow precipitate may vary under different conditions of precipitation. Further, it is altogether not out of the question that in Neumann's method the ammonium phosphomolybdate is not absolutely insoluble in the liquid from which it is thrown down, in which case the filtrate from the yellow precipitate must still contain some phosphorus. Moreover, the yellow precipitate formed may, though to a small extent, be lost in the course of the various manipulations incident to that method. This may especially be due to the effect of the wash water on the yellow precipitate. It is with these questions that we shall chiefly be concerned in this paper.

[10] *Z. analyt. Chem.*, **28**, 141 (1889).

[11] Jodidi, S. L., *Journ. Amer. Chem. Soc.*, **37**, 1708 (1915).

Data Concerning the Solubility of the Ammonium Phosphomolybdate Precipitate in Water.

A review of the literature in question shows that there is considerable divergency of opinion as to whether or not the yellow precipitate is soluble in water. Hundeshagen,[12] who was one of the first to investigate into the nature of the ammonium phosphomolybdate precipitate with the object in view of elaborating a volumetric method for the estimation of phosphoric acid, is of the opinion that only ice-cold water should be used for the washing of the yellow precipitate, since in case water of room temperature is used it is hard to prevent traces of the precipitate from going through the filter or into the solution.

Pemberton [13] draws from his experiments the conclusion that there is no danger of loss in washing the yellow precipitate with water.

Isbert and Stutzer [14] hold that the ammonium phosphomolybdate is insoluble in cold water.

Eggertz [15] states that the solubility of the ammonium phosphomolybdate in pure water is 1 : 10,000, to which Hundeshagen remarks that in his experience the solubility is considerably greater.

Neumann [16] maintains that the yellow precipitate is altogether insoluble in the liquid in which it was thrown down, and is so difficultly soluble in very cold water that only a minute amount of it is dissolved after it has been in contact with the water for a long while.

Wardlaw [17] states that by evaporating down the washings extremely slight amounts of the precipitate were found to have dissolved.

Our observations made during the work reported in the first paper [18] of this series pointed to slight solubility of the ammonium phosphomolybdate in water. It seemed desirable quantitatively to ascertain just how much of the yellow precipitate is dissolved or otherwise lost in the course of the various manipulations.

[12] *Z. analyt. Chem.*, **28**, 164 (1889).
[13] *Journ. Amer. Chem. Soc.*, **15**, 386 (1893).
[14] *Z. analyt. Chem.*, **36**, 583 (1897).
[15] *Z. analyt. Chem.*, **28**, 161 (1889).
[16] *Z. physiol. Chem.*, **37**, 132 (1902–03).
[17] *Jour. Proc. Roy. Soc. New South Wales*, **48**, 83 (1914).
[18] *Jour. Amer. Chem. Soc.*, **37**, 1708 (1915).

In the washing of the yellow precipitate several factors are evidently involved; namely, the quantity of wash water applied, its temperature, the duration of its contact with the precipitate, which again in some measure depends upon the physical properties of the yellow precipitate as well as of the filter. While the operator has full control of the first two factors (quantity of wash water and its temperature), he is confronted with the fact that the last-named factors are more or less incidental.

EXPERIMENTAL.

For our experiments we have used the phosphates of sodium, potassium, and ammonium as well as the free phosphoric acid. The data obtained according to Neumann's acidimetric method were calculated to the results found by the usual gravimetric [19] method in which the phosphoric acid is precipitated as magnesium ammonium phosphate and weighed as pyrophosphate. Inasmuch as more recent work of Gooch,[20] Neubauer,[21] Järvinen,[22] Schmitz,[23] Jörgensen,[24] and others has demonstrated that when the phosphoric acid is precipitated in the cold it is quite difficult to obtain a pure precipitate of $MgNH_4PO_4$, which is, however, the case when the precipitation takes place in a hot solution, it was deemed necessary to check up all of the analyses made according to the gravimetric method as given in Fresenius by the newer method of Schmitz.[25] Both methods were further checked up by the conversion of the alkali orthophosphates into the corresponding pyrophosphates and metaphosphates respectively. In order to avoid errors due to imperfectly-graduated vessels, we have used throughout these experiments the same burette of 50 c.c. and the same flask of 250 c.c. which were found to be accurately graduated and to closely agree with each other. Further, we have used for each series of experiments the same stock solution, which was usually sufficiently dilute and kept in a well-stoppered flask. Whenever possible the portions of the solution to be analyzed were simultaneously measured out. Again, in order to exclude

[19] Fresenius, "Quantitative Anal.," 6th edition, 1, 402 (1903).
[20] *Z. anorg. Chem.*, **20**, 135 (1899).
[21] *Z. angew. Chem.*, **1896**, 439.
[22] *Z. anal. Chem.*, **43**, 279 (1904); **44**, 333 (1905).
[23] *Ibid.*, **45**, 512 (1906).
[24] *Ibid.*, **45**, 278 (1906).
[25] *Loc. cit.*

the influence of individual errors as much as possible it was deemed advisable to base the conclusions upon a considerable number of, in the most cases, concordant analyses, the average of which could be considered as reliable. The precipitation of the ammonium phosphomolybdate was accomplished exactly in the manner described in a previous paper.[26] When modifications were applied they will be mentioned.

SERIES A.

Nine grammes of primary potassium phosphate (KH_2PO_4) were dissolved in water, the solution made up to about five litres and thoroughly shaken. Eight portions of this solution of 250 c.c. each were subjected to gravimetric analysis according to Fresenius's method, eight like portions according to Schmitz's method, while five portions of 50 c.c. each were converted into metaphosphate by ignition. The data obtained are summarized in the table below.

TABLE I.

Number of analysis	Found			Number of analysis	Found		
	(*a*) $Mg_2P_2O_7$ (Fresenius)	(*b*) $Mg_2P_2O_7$ (Schmitz)	(*c*) KPO_3		(*a*) $Mg_2P_2O_7$ (Fresenius)	(*b*) $Mg_2P_2O_7$ (Schmitz)	(*c*) KPO_3
	Gramme	*Gramme*	*Gramme*		*Gramme*	*Gramme*	*Gramme*
1.....	0.3697	0.3697	0.0783	5.....	0.3696	0.3672	0.0782
2.....	0.3697	0.3688	0.0778	6.....	0.3698	0.3679	.....
3.....	0.3689	0.3689	0.0785	7.....	0.3699	0.3679	.....
4.....	0.3694	0.3677	0.0785	8.....	0.3699	0.3682	.....
Mean..	.....	.....	.....	.....	0.3696	0.3683	0.0783

Hence, 1 c.c. of the solution contains 0.41171 mg. P (*a*), or 0.41025 mg. P (*b*), or 0.41106 mg. P (*c*).

Titration According to Neumann's Method.

Thirty portions of the above solution of 25 c.c. each were subjected to titration by Neumann's method. It is a matter of course that all numbers of this as well as of the other series were treated exactly in the same manner, with the only difference that the quantities of water applied for washing the yellow precipitate varied with the different numbers. The data are presented in

[26] Jodidi, S. L., *Journ. Amer. Chem. Soc.*, 37, 1709 (1915).

Table II. The column of this table which gives $\frac{n}{2}$ NaOH used needs some explanation, which is also true of the corresponding tables of the other series. Gregersen [27] has pointed out that in Neumann's method carbon dioxide present in the liquids to be titrated is a source of error tending somewhat to increase the quantity of $\frac{n}{2}$ NaOH necessary for the neutralization of the ammonium phosphomolybdate.

TABLE II.

$\frac{n}{2}$ NaOH used C.c.	[28]Factor based on estimation of (a) $Mg_2P_2O_7$ (Fresenius)	(b) $Mg_2P_2O_7$ (Schmitz)	(c) KPO_3	$\frac{n}{2}$ NaOH used C.c.	Factor based on estimation of (a) $Mg_2P_2O_7$ (Fresenius)	(b) $Mg_2P_2O_7$ (Schmitz)	(c) KPO_3
17.83	0.577	0.575	0.576	18.10	0.569	0.567	0.568
17.73	0.581	0.579	0.580	17.80	0.578	0.576	0.577
17.53	0.587	0.585	0.586	18.10	0.569	0.567	0.568
17.85	0.577	0.575	0.576	17.75	0.580	0.578	0.579
17.73	0.581	0.579	0.580	18.35	0.561	0.559	0.560
17.95	0.573	0.571	0.573	17.75	0.580	0.578	0.579
18.00	0.572	0.570	0.571	.....	.....	.....	.....
17.90	0.575	0.573	0.574	.....	.....	.....	.....
	Mean of Nos. 1–8				Mean of Nos. 9–14		
17.81	0.578	0.576	0.577	17.97	0.573	0.571	0.572
17.93	0.574	0.572	0.573	18.30	0.562	0.560	0.562
17.90	0.575	0.573	0.574	18.10	0.569	0.567	0.568
17.80	0.578	0.576	0.577	18.17	0.566	0.564	0.566
18.05	0.570	0.568	0.569	18.05	0.570	0.568	0.569
18.00	0.572	0.570	0.571	18.08	0.569	0.567	0.568
18.05	0.570	0.568	0.569	18.10	0.569	0.567	0.568
17.99	0.572	0.570	0.571	18.20	0.566	0.5644	0.565
18.00	0.572	0.570	0.571	18.07	0.570	0.568	0.569
	Mean of Nos. 15–22				Mean of Nos. 23–30		
17.96	0.573	0.571	0.572	18.13	0.568	0.566	0.567

In order to eliminate this error he recommends to overtitrate the solution of the yellow precipitate in $\frac{n}{2}$ NaOH with from ½ c.c. to 1 c.c. of $\frac{n}{2}$ H_2SO_4, to drive off now the carbon dioxide by boiling, to cool and titrate back with $\frac{n}{2}$ NaOH. This, however, in-

[27] *Z. physiol. Chem.*, 53, 455 (1907).

[28] The factor in this table, like in the others, was calculated to the average of the gravimetric analysis (see Table I). No. 1, *e.g.*, has the factor $0.41171 \times \frac{17}{13} = 0.577$.

creases necessarily the time required for the titration of each individual analysis, aside from the fact that the liquid acidified with $\frac{n}{2}$ H_2SO_4 has the tendency somewhat to bump while boiling. Inasmuch as in Neumann's method it is indispensable to ascertain as to whether or not the reagents are free from phosphoric acid, the writers have found it to be more convenient to run a "blank" (preferably several "blanks") and to subtract the amount of standard alkali applied for neutralization of the "blank" from the result of the analysis proper. The figure secured for the blank analysis can advantageously be applied to a series of analyses, and it is evident that it does away with the necessity of removing carbon dioxide from the liquid to be titrated, since both the analysis and the "blank" contain practically the same amount of carbon dioxide. Thus eight blank analyses were made, in each of which there were employed 125 c.c. of distilled water, 10 c.c. of acid mixture, 75 c.c. of 50 per cent. ammonium nitrate, 40 c.c. of 10 per cent. ammonium molybdate, and one S. & S. filter of 12½ cm. diameter which was washed to neutrality (with either 50 c.c. or 150 c.c. of distilled water three times). Now each flask containing one washed filter received 150 c.c. of distilled water for reducing the filter to pulp, then 6 c.c. $\frac{n}{2}$ NaOH, whereupon contents were boiled for from fifteen to twenty minutes, cooled, made up to the original volume, and titrated. The blanks required for their neutralization on the average of concordant analyses 0.20 c.c. $\frac{n}{2}$ NaOH. The latter figure, which was applied to several series of analyses, was subtracted from the standard alkali used for each individual analysis and the so corrected figure recorded in the column in question.

In glancing over the table we can readily see that the factor is to a certain degree influenced by the amount of water applied for washing the yellow precipitate. Numbers 1 to 8, the ammonium phosphomolybdate of which was washed with 150 c.c. of water, the washing being repeated four times, have the average factors of 0.578 (*a*), 0.576 (*b*), 0.577 (*c*); numbers 15 to 22, whose yellow precipitate was washed with 100 c.c. of water three times, have the average factors of 0.573 (*a*), 0.571 (*b*), 0.572 (*c*); while numbers 23 to 30, in which the washing of the yellow precipitate with 50 c.c. of water was performed three times, gave

the smallest average factors of 0.568 (*a*), 0.566 (*b*), 0.567 (*c*). On the other hand, however, the numbers 9 to 14 and 15 to 22, the yellow precipitate of which was washed three times with 150 c.c. and 100 c.c. of water respectively, yielded the identical factors.

SERIES B.

Eight grammes of secondary ammonium phosphate [$(NH_4)_2HPO_4$] were dissolved in water, made up to about five litres, and the solution thoroughly shaken. In eight portions of this solution of 250 c.c. each the phosphorus was estimated according to the method of Fresenius, and in as many portions according to the method of Schmitz. The results are expressed in the following table:

TABLE III.

Number of analysis	$Mg_2P_2O_7$ found		Number of analysis	$Mg_2P_2O_7$ found	
	(Presenius)	(Schmitz)		(Presenius)	(Schmitz)
	Gramme	*Gramme*		*Gramme*	*Gramme*
1.....	0.3393	0.3382	5.....	0.3398	0.3386
2.....	0.3388	0.3389	6.....	0.3397	0.3385
3.....	0.3391	0.3386	7.....	0.3404	0.3386
4.....	0.3386	0.3388	8.....	0.3385	0.3384
Mean (1-8).....				0.3393	0.3386

Titration According to Neumann's Method.

Thirty-one portions of the above solution of 50 c.c. each were worked up according to Neumann's method. It goes without saying that the ammonium phosphomolybdate, prior to its titration, must be washed free from the adhering sulphuric and nitric acids with ice-cold water. Neumann [29] states that in order to obtain entirely neutral reaction of the filtrate the yellow precipitate has to be washed with 150 c.c. of ice-cold water, the washing being repeated from three to four times. As a matter of fact we have found that it is sufficient to wash the yellow precipitate on a 12½ cm. folded filter three times with but 50 c.c. of water. The filtrate was repeatedly tried by us with sensitive neutral litmus paper and was found to be neutral.

The results in question are summarized in Table IV.

[29] *Z. physiol. Chem.*, 37, 132 and 135 (1902-03).

TABLE IV.

$\frac{n}{2}$ NaOH used C.c.	Factor based on estimation of		$\frac{n}{2}$ NaOH used C.c.	Factor based on estimation of	
	(*a*) $Mg_2P_2O_7$ (Fresenius)	(*b*) $Mg_2P_2O_7$ (Schmitz)		(*a*) $Mg_2P_2O_7$ (Fresenius)	(*b*) $Mg_2P_2O_7$ (Schmitz)
32.80	0.576	0.575	32.85	0.575	0.574
33.10	0.571	0.570	32.93	0.574	0.572
33.22	0.569	0.568	32.95	0.573	0.572
32.98	0.573	0.572	32.88	0.575	0.573
32.74	0.577	0.576	33.01	0.572	0.571
33.00	0.573	0.571	32.95	0.573	0.572
32.74	0.577	0.576	32.92	0.574	0.573
32.74	0.577	0.576	32.85	0.575	0.574
32.70	0.578	0.577	32.90	0.574	0.573
Mean of Nos. 1–9			Mean of Nos. 10–18		
32.89	0.575	0.574	32.92	0.574	0.573
33.20	0.569	0.568	33.15	0.570	0.569
33.32	0.567	0.566	33.15	0.570	0.569
33.20	0.569	0.568	33.17	0.570	0.569
33.22	0.569	0.568	33.15	0.570	0.569
33.37	0.566	0.565	33.12	0.571	0.569
33.15	0.570	0.569	33.00	0.573	0.571
Mean of Nos. 19–30			33.19	0.569	0.568

An examination of the table reveals the fact that, while the influence on the factor of the amount of water employed for washing the yellow precipitate is small, yet it is distinct. Thus, numbers 1 to 9, the yellow precipitate of which was washed with 150 c.c. of ice-cold water, the washing being repeated three times, yielded the average factors of 0.575 (*a*), 0.574 (*b*). At the same time numbers 10 to 18, in which the washing of the yellow precipitate with 100 c.c. of water was performed three times, gave the average factors of 0.574 (*a*), 0.573 (*b*); while numbers 19 to 30, whose precipitate was washed with but 50 c.c. of water three times, gave the smallest average factors of 0.569 (*a*), 0.568 (*b*). On the whole the data of this series confirm the results of Series A, showing that, within certain limits, the factor is the higher the more water is employed for washing the yellow precipitate, and *vice versa*. In this connection it may be worth while here to mention that of all manipulations incident to Neumann's method the washing of the yellow precipitate in accordance with Neumann's directions is an operation not only tiresome

but one requiring considerable time. The observation that it is sufficient to wash the phosphomolybdate of ammonia with three times 50 c.c. of water (instead of three or four times 150 c.c. of water) in order to obtain a neutral filtrate enables one to save more than half the time which was originally necessary for washing the yellow precipitate. We have also found that whenever the phosphoric acid is present in inorganic form it is advantageous to use, for the formation of the yellow precipitate and its washing, a round bottom flask of some 300 c.c. capacity, instead of a flask of from 500 c.c. to 750 c.c., as is ordinarily used in Neumann's method. In such cases where previous oxidation of organic matter with the acid mixture has to take place the substance is, on oxidation in the larger flask, transferred to the 300 c.c. flask with the aid of distilled water, which is, at all events, to be added before the formation of the ammonium phosphomolybdate takes place. The 300 c.c. flask is easier to handle during the repeated filtrations, and the yellow precipitate in it is more readily washed free from the adhering acids with a comparatively small amount of distilled water.

SERIES C.

A solution of 15 grammes of crystallized disodium hydrogen phosphate[30] in water which was made up to five litres was employed for the trials of this series. Of this solution eight 250 c.c. portions were analyzed gravimetrically according to Fresenius's method, eight like portions according to Schmitz's method, while five 50 c.c. portions were converted into sodium pyrophosphate by ignition. The results are recorded in the table below.

TABLE V.

Number of analysis	Found			Number of analysis	Found		
	(*a*) $Mg_2P_2O_7$ (Fresenius)	(*b*) $Mg_2P_2O_7$ (Schmitz)	(*c*) $Na_4P_2O_7$		(*a*) $Mg_2P_2O_7$ (Fresenius)	(*b*) $Mg_2P_2O_7$ (Schmitz)	(*c*) $Na_4P_2O_7$
	Gramme	*Gramme*	*Gramme*		*Gramme*	*Gramme*	*Gramme*
1.....	0.2623	0.2626	0.0630	5.....	0.2625	0.2617	0.0630
2.....	0.2618	0.2623	0.0630	6.....	0.2631	0.2621	.....
3.....	0.2630	0.2627	0.0630	7.....	0.2631	0.2618	.....
4.....	0.2630	0.2630	0.0632	8.....	0.2630	0.2614	.....
Mean.....					0.2627	0.2622	0.0630

[30] The crystals have in part lost their water of crystallization.

Titration According to Neumann's Method.

Twenty-four portions of the above solution of 50 c.c. each were titrated according to Neumann. The data in question are contained in Table VI. The figures in columns 1 and 5 of the table represent the standard alkali used for each individual analysis minus 0.20 c.c. $\frac{n}{2}$ NaOH required for neutralization of the acidity found in the blank analysis. In connection with the blank analysis it may be mentioned here that on addition of ammonium molybdate to the heated mixture of water, acid mixture, and ammonium nitrate the solution remained water-clear. On standing it gave neither a precipitate nor even a faint yellow color, showing that the reagents were free from phosphoric acid. Since, however, the blank analyses yielded an acidity equivalent to 0.20 c.c. $\frac{n}{2}$ NaOH it was logical to suppose, as we did, that the acidity was caused by the action of the alkali on the filter paper. This was actually confirmed by the direct experiment. Each of six round-bottom flasks received a S. & S. filter (of 12½ cm. diameter) which was reduced to pulp with the aid of 150 c.c. of distilled water. The flasks, with their contents, to each of which 10 c.c. $\frac{n}{5}$ NaOH had been added, were now heated to the boiling-point and kept boiling for from fifteen to twenty minutes, whereupon they were cooled, filled up to original volume, and titrated back with $\frac{n}{5}$ H_2SO_4, phenolphthalein being used as indicator. On the average of concordant titrations, each filter required for its neutralization 0.49 c.c. $\frac{n}{5}$ NaOH, which is identical with the acidity of the blank analyses (0.20 c.c. $\frac{n}{2}$ NaOH). When this experiment was repeated, with the only difference that the filter pulp was boiled *without* the addition of 10 c.c. $\frac{n}{5}$ NaOH, it was found that the filter pulp gave neutral reaction in each case, showing that the filters and water were neutral.

A glance at the table shows that numbers 1 to 12 and numbers 13 to 24, whose yellow precipitate was washed with three times 150 c.c. and 50 c.c. of ice-cooled water respectively, have the identical average factors, thus showing in this case no visible influence of the quantity of wash water on the factor.

TABLE VI.

$\frac{n}{2}$ NaOH used C.c.	Factor based on estimation of			$\frac{n}{2}$ NaOH used C.c.	Factor based on estimation of		
	(a) $Mg_2P_2O_7$ (Fresenius)	(b) $Mg_2P_2O_7$ (Schmitz)	(c) $Na_4P_2O_7$		(a) $Mg_2P_2O_7$ (Fresenius)	(b) $Mg_2P_2O_7$ (Schmitz)	(c) $Na_4P_2O_7$
25.65	0.570	0.569	0.572	25.52	0.573	0.572	0.575
25.45	0.575	0.574	0.577	25.65	0.570	0.569	0.572
25.65	0.570	0.569	0.572	25.65	0.570	0.569	0.572
25.63	0.571	0.570	0.573	25.62	0.571	0.570	0.573
25.60	0.572	0.571	0.574	25.58	0.572	0.571	0.574
25.65	0.570	0.569	0.572	25.61	0.571	0.570	0.573
Mean of Nos. 1–12.....			.....	25.61	0.571	0.570	0.573
25.45	0.575	0.574	0.577	25.80	0.567	0.566	0.569
25.58	0.572	0.571	0.574	25.60	0.572	0.570	0.574
25.71	0.569	0.568	0.571	25.53	0.573	0.572	0.575
25.62	0.571	0.570	0.573	25.62	0.571	0.570	0.573
25.60	0.572	0.570	0.574	25.65	0.570	0.569	0.572
25.60	0.572	0.570	0.574	25.50	0.574	0.573	0.576
Mean of Nos. 13–24.....			.....	25.61	0.571	0.570	0.573

SERIES D.

Ten grammes of 85 per cent. phosphoric acid made up to five litres were used for the trials of this series. In seven 100 c.c. portions of this solution the phosphorus was estimated gravimetrically according to the method of Fresenius, and in eight like portions according to the method of Schmitz, with the results summarized in Table VII.

TABLE VII.

Number of analysis	$Mg_2P_2O_7$ found		Number of analysis	$Mg_2P_2O_7$ found	
	(Fresenius)	(Schmitz)		(Fresenius)	(Schmitz)
	Gramme	*Gramme*		*Gramme*	*Gramme*
1.....	0.2096	0.2085	5.....	0.2097	0.2090
2.....	0.2099	0.2079	6.....	0.2099	0.2090
3.....	0.2102	0.2085	7.....	0.2100	0.2086
4.....	0.2102	0.2086	8.....	.....	0.2088
Mean.....				0.2099	0.2086

Twenty-six portions of the same solution of 25 c.c. each were treated according to Neumann. The data are recorded in Table VIII.

TABLE VIII.

$\frac{n}{2}$ NaOH used C.c.	Factor based on estimation of		$\frac{n}{2}$ NaOH used C.c.	Factor based on estimation of	
	(a) $Mg_2P_2O_7$ (Fresenius)	(b) $Mg_2P_2O_7$ (Schmitz)		(a) $Mg_2P_2O_7$ (Fresenius)	(b) $Mg_2P_2O_7$ (Schmitz)
25.28	0.578	0.574	25.25	0.579	0.575
25.25	0.579	0.575	25.38	0.576	0.572
25.18	0.580	0.577	25.30	0.578	0.574
25.30	0.578	0.574	25.15	0.581	0.577
25.28	0.578	0.574	25.30	0.578	0.574
Mean of Nos. 1–10.....			25.27	0.578	0.575
25.32	0.577	0.574	25.30	0.578	0.574
25.42	0.575	0.571	25.40	0.575	0.572
25.30	0.578	0.574	25.10	0.582	0.579
25.35	0.577	0.573	25.40	0.575	0.572
Mean of Nos. 11–18.....			25.32	0.577	0.574
25.70	0.569	0.565	25.70	0.569	0.565
25.75	0.568	0.564	25.60	0.571	0.568
25.73	0.568	0.564	25.70	0.569	0.565
25.80	0.566	0.563	25.85	0.565	0.562
Mean of Nos. 19–26.....			25.73	0.568	0.565

In glancing over the table we can readily see that the numbers 1 to 10, the yellow precipitate of which was washed with 150 c.c. of ice-cooled water four times, gave the average factors of 0.578 (*a*) and 0.575 (*b*); the numbers 11 to 18, whose yellow precipitate was washed with 100 c.c. of water three times, yielded the average factors of 0.577 (*a*) and 0.574 (*b*); while the numbers 19 to 26, whose precipitate was washed with but 50 c.c. of water three times, yielded the smallest average factors of 0.568 (*a*) and 0.565 (*b*). Thus this series corroborates the results of Series A and B, in that the amount of wash water has a distinct though small influence on the factor.

SERIES E.

Pulverized, oven-dried disodium hydrogen phosphate (37.5 grammes) dissolved in water and made up to about nine litres was used for the experiments of this series. In ten portions of this solution of 50 c.c. each the phosphorus was estimated gravimetrically according to the method of Fresenius, in eight like portions according to Schmitz, while in other three portions the phos-

phorus was by ignition converted into pyrophosphate. The results are recorded in Table IX.

TABLE IX.

Number of analysis	Found			Number of analysis	Found		
	(a) $Mg_2P_2O_7$ (Presenius)	(b) $Mg_2P_2O_7$ (Schmitz)	(c) $Na_4P_2O_7$		(a) $Mg_2P_2O_7$ (Presenius)	(b) $Mg_2P_2O_7$ (Schmitz)	(c) $Na_4P_2O_7$
	Gramme	*Gramme*	*Gramme*		*Gramme*	*Gramme*	*Gramme*
1.....	0.1632	0.1627	.....	6.....	0.1642	0.1629	0.1950
2.....	0.1650	0.1627	.....	7.....	0.1632	0.1628	0.1952
3.....	0.1631	0.1627	.....	8.....	0.1637	0.1630	0.1942
4.....	0.1639	0.1632	.....	9.....	0.1634	.....	.....
5.....	0.1647	0.1628	.....	10.....	0.1628	.....	.....
Mean.....					0.1637	0.1629	0.1948

From the analytical data it follows that 1 c.c. of the solution contains respectively 0.91184, 0.90727, and 0.90809 mg. P according to methods (*a*), (*b*), and (*c*).

Thirty other portions of the above solution of 10 c.c. each were treated according to Neumann's method. The data are summarized in Table X.

TABLE X.

$\frac{n}{2}$ NaOH used *C.c.*	Factor based on estimation of			$\frac{n}{2}$ NaOH used *C.c.*	Factor based on estimation of		
	(a) $Mg_2P_2O_7$ (Presenius)	(b) $Mg_2P_2O_7$ (Schmitz)	(c) $Na_4P_2O_7$		(a) $Mg_2P_2O_7$ (Presenius)	(b) $Mg_2P_2O_7$ (Schmitz)	(c) $Na_4P_2O_7$
15.80	0.577	0.574	0.575	15.71	0.580	0.578	0.578
15.80	0.577	0.574	0.575	15.80	0.577	0.574	0.575
15.81	0.577	0.574	0.575	15.80	0.577	0.574	0.575
15.78	0.578	0.575	0.575	15.74	0.579	0.576	0.576
15.80	0.577	0.574	0.575	15.79	0.577	0.575	0.575
15.78	0.578	0.575	0.575	15.80	0.577	0.574	0.575
15.78	0.578	0.575	0.575	15.90	0.573	0.571	0.571
15.70	0.581	0.578	0.578	.....	.....	.....	.....
Mean of Nos. 1–15.....				15.79	0.577	0.575	0.575
15.71	0.580	0.578	0.578	15.70	0.581	0.578	0.578
15.71	0.580	0.578	0.578	15.76	0.579	0.576	0.576
15.69	0.581	0.578	0.578	15.68	0.582	0.579	0.579
15.62	0.584	0.581	0.581	15.72	0.580	0.577	0.578
15.62	0.584	0.581	0.581	15.68	0.582	0.579	0.579
15.71	0.580	0.578	0.578	15.70	0.581	0.578	0.578
15.70	0.581	0.578	0.578	15.70	0.581	0.578	0.578
15.68	0.582	0.579	0.579	.....	.....	.....	.....
Mean of Nos. 16–30.....				15.69	0.581	0.578	0.578

An examination of the table reveals the fact that the individual factors obtained by method (*a*) agree very well with each other. This holds also good for the individual factors secured by methods (*b*) and (*c*). The numbers 1 to 15, whose yellow precipitate was washed with 150 c.c. of ice-cold water, the washing being performed three times, yielded the average factors 0.577 (*a*), 0.575 (*b*), and 0.575 (*c*), while the numbers 16 to 30, whose precipitate was washed with 150 c.c. of water four times, gave the higher average factors 0.581 (*a*), 0.578 (*b*) and 0.578 (c). Thus the figures of this series confirm the results secured in Series A, B, and D in that, within certain limits, the factor is the higher the more water is used for washing the yellow precipitate, and *vice versa*.

The average factors for all five series (based on all three methods) were as follows:

0.577, when precipitate was washed with four times 150 c.c. of ice-cold water;
0.573, when precipitate was washed with three times 150 c.c. of ice-cold water;
0.573, when precipitate was washed with three times 100 c.c. of ice-cold water;
0.568, when precipitate was washed with three times 50 c.c. of ice-cold water.

The mean factors in the various series—despite the fact that they were washed with the same amount of water—were rather subjected to some variation. This must be ascribed to the fact that the factors are influenced not only by the amount but also by the temperature of the wash [31] water, as well as by the time of contact of the water with the yellow precipitate, which in some measure depends upon the physical qualities of the filter and of the yellow precipitate itself. Since we are not fully in control of the latter two factors, it is obvious that the time during which the yellow precipitate is in contact with the wash water will vary to a certain degree, while, on the other hand, even with the greatest care it is not infrequently impossible to prevent traces of the yellow precipitate from going through the filter. On the whole, however, it seems safe to state that the tendency of the factor to grow,

[31] The temperature of the wash water which was cooled in a refrigerator was not quite uniform, because of the somewhat changing temperature within the refrigerator.

within certain limits, with increasing amounts of wash water follows from the data at hand.

The latter conclusion made it appear of interest quantitatively to determine the amount of phosphorus which is lost in filtrate and washings from the yellow precipitate. It seemed probable that the washings (plus filtrate) would contain different amounts of phosphorus when the yellow precipitate is washed with different quantities of water. Hence experiments were carried out for which a disodium hydrogen phosphate solution was used, 1 c.c. of which was gravimetrically found to contain 0.90907 milligramme phosphorus. In six portions of this solution of 20 c.c. each the ammonium phosphomolybdate precipitate was obtained exactly as outlined elsewhere,[82] and, on filtration, was washed with 150 c.c. of ice-cold water, the washing being repeated four times. The six filtrates and the corresponding washings were combined and evaporated on the steam-bath. As the concentration went on the liquid gradually became intensely yellow. The evaporation was continued to beginning crystallization, when the residue was quantitatively transferred to a round-bottom flask, cooled, dissolved in water under addition of dilute ammonia, and filtered until perfectly clear. This filtrate was now neutralized with nitric acid, 30 c.c. more of concentrated nitric acid were added (total volume was now about 500 c.c.) and heated to 80° C. On standing, the yellow precipitate came slowly down. It was filtered out (after about one hour), washed with ice-cold water until wash water was neutral, and titrated after the ammonia had been driven off. The recovered yellow precipitate required 1.85 c.c. $\frac{n}{2}$ NaOH for its neutralization. Filtrate and washings from this precipitate were combined, again evaporated and treated as outlined. The yellow precipitate (second recovery) now obtained required 0.30 c.c. $\frac{n}{2}$ NaOH. Filtrate and washings from the second precipitate, when evaporated and treated again as outlined, did not give any further precipitate. This experiment was repeated with varying amounts of the phosphorus solution. The results are recorded in Table XI.

[82] *Jour. Amer. Chem. Soc.*, 37, 1709 (1915).

TABLE XI.

Loss of Phosphorus in Filtrate and Washings.

No.	Na_2HPO_4 used		Yellow precipitate washed with ice-cold water		The yellow precipitate (recovered from filtrates and washings) required for its neutralization	Corresponding total phosphorus	
	C.c.	Corresponding phosphorus Mgrs.	*C.c.*	Times	$\frac{n}{2}$ NaOH, *C.c.*	Mgrs.	Per cent. of phosphorus applied
1.....	6×20	109.0884	150	4	1.85 (First recovery) 0.30 (Second recovery)	1.2255	1.12
2.....	3×20	54.5442	150	4	1.02	0.5814	1.07
3.....	6×15	81.8163	150	4	2.08 (First recovery) 0.83 (Second recovery)	1.6587	2.03
4.....	6×10	54.5442	150	4	2.31 (First recovery) 0.15 (Second recovery)	1.4022	2.57
5.....	6×5	27.2721	150	4	1.70 (First recovery) 0.19 (Second recovery)	1.0773	3.95
6.....	6×20	109.0884	50	3	1.50 (First recovery) 0.20 (Second recovery)	0.9690	0.89
7.....	6×15	81.8163	50	3	1.80 (First recovery) 0.55 (Second recovery)	1.3395	1.64
8.....	6×10	54.5442	50	3	1.25 (First recovery) 0.40 (Second recovery)	0.9405	1.72
9.....	6×5	27.2721	50	3	1.08 (First recovery) 0.45 (Second recovery)	0.8721	3.20

TABLE XII.

No.	Na_2HPO_4 used		Yellow precipitate washed with ice-cold water		The yellow precipitate (recovered from filtrate only) required for its neutralization	The yellow precipitate (recovered from washings only) required for its neutralization	Corresponding phosphorus	
	C.c.	Corresponding phosphorus Mgs.	*C.c.*	Times	$\frac{n}{2}$ NaOH *C.c.*	$\frac{n}{2}$ NaOH *C.c.*	Mgs.	Per cent. of phosphorus applied
1.....	10×20	181.814	150	4	1.26	....	0.7182	0.40
					....	1.83	1.0431	0.57
2.....	10×20	181.814	50	3	1.40	....	0.7980	0.44
					....	1.10	0.6270	0.34
3.....	10×10	90.907	150	4	1.23	....	0.7011	0.77
					....	1.33	0.7581	0.83
4.....	10×10	90.907	50	3	1.18	....	0.6726	0.74
					....	1.03	0.5871	0.65

It seemed also desirable to ascertain whether and how much of phosphorus is lost in the *filtrate* from the yellow precipitate only. Hence experiments were made similar to those recorded in Table XI, with the difference that the filtrates on the one hand and the washings on the other were separately evaporated and treated as outlined above. The results are summarized in Table XII.

CONCLUSIONS.

1. The factor used for the calculation of phosphoric acid in Neumann's method is to a certain degree influenced by the amount of water used for washing the ammonium phosphomolybdate precipitate. The larger the amount of wash water, the higher is the factor within certain limits, and *vice versa*.

2. When the yellow precipitate was washed with four times 150 c.c. of ice-cold water, the losses of phosphorus in filtrate plus washings ranged from 1.07 to 3.95 per cent. of the phosphorus employed. By washing the precipitate with but three times 50 c.c. of water the corresponding losses were smaller; namely, they ranged from 0.89 to 3.20 per cent. (Table XI). This explains in part why the factor rises with increasing amounts of wash water.

3. The more substance (phosphorus) is employed in Neumann's method, the smaller is the percentage of phosphorus lost in filtrate and washings, and *vice versa*.

4. The ammonium phosphomolybdate is not absolutely insoluble in the liquid from which it is precipitated, the losses of phosphorus ranging in the experiments reported from 0.40 to 0.77 per cent. of the phosphorus employed (Table XII).

5. Instead of washing the ammonium phosphomolybate precipitate with 150 c.c. of ice-cold water, the washing being repeated from three to four times, as is recommended by Neumann, it is sufficient to wash it with three times 50 c.c. of water, which enables one to save time and labor. It is, further, more convenient to use, for the formation of the yellow precipitate and its washings, a 300 c.c. round-bottom flask, instead of a flask of from 500 to 750 c.c., as is commonly used in Neumann's method. The latter flask is, however, to be used for oxidation of organic matter, if present.

WASHINGTON, D. C.

External Corrosion of Cast-iron Pipe. M. R. PUGH. (*The American Gas Light Journal,* vol. ciii, No 5, August 2, 1915.)—In a paper read before the American Society of Civil Engineers the author mentions instances, both here and abroad, in which cast-iron water-pipe has remained in perfect condition after a hundred years' service or more when laid underground or immersed in fresh water. When, however, they have been laid in salt marshes or immersed in sea water their useful life is measured by a few years only. From a comprehensive analysis of the subject the following conclusions are reached: (1) Under ordinary conditions of soil, cast-iron pipe has a probable life of from one to three centuries, so far as external corrosion is concerned. (2) Under certain soil conditions, such as salt marshes or saline soils, cast-iron pipe may be rendered useless in from seven to twenty years. (3) At times cinder and slag fills may exert a strongly deleterious influence. Acid mine waters are also destructive. (4) Substituting wrought iron or steel pipe for cast iron is ineffectual. Cast iron will outlast the others. (5) Remedies fall under four heads: (*a*) Increasing the skin resistance of cast iron; (*b*) utilizing the protective influence of alkalies by surrounding the pipe with lime or cement where practicable; (*c*) exclusion of acids, salt, or air; (*d*) galvanizing the cast-iron pipe, thus protecting it at the expense of the zinc.

The Thermal Efficiency of the Electric Furnace. W. McA. JOHNSON. (*Proceedings of the Engineers' Society of Western Pennsylvania,* vol. 31, No. 6, July, 1915.)—It does not appear commercially possible to use the electric furnace in direct competition with the coal- or gas-fired furnace. A ton of coal of 11,147 B. T. U.'s per pound has the same number of heat units as a horse-power year. A short ton of coal in the Pittsburgh district costs about one dollar. A horse-power year will cost in the same locality from $30 to $60. This means that the cost of electrically-generated heat in this district is from thirty to sixty times as great as the cost of heat in coal. In Norway energy is sold at ridiculously low prices. There is a great deal of water-power running to waste. It has a high head, a nearly constant flow, and the cost of installation is low. On reliable information it is stated that contracts are made at as low a figure as $5 per horse-power year. But even under these extremely favorable conditions the electric furnace using iron ore and burning out pig iron has not been a commercial success. There are many iron blast furnaces using coke and charcoal in Norway and Sweden and only a few electric pig-iron furnaces. If in these countries the electric pig-iron furnace cannot compete, or compete only with difficulty, we cannot hope for it to compete in Chicago or Pittsburgh.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

ANTENNA RESISTANCE.

By L. W. Austin.

[ABSTRACT.]

THE resistance of a radiotelegraphic antenna may be divided into three parts: first, the ohmic resistance of the wires; second, the so-called radiation resistance; and, third, the so-called earth resistance. The first is generally negligible where a sufficient number of wires in parallel is used. The second is derived from the expression for the radiated energy of an antenna, which is

$$E = 160\pi^2 \frac{h^2}{\lambda^2} \cdot I_s^2$$

where h represents the height to the centre of capacity of the antenna, λ the wave-length, and I_s the current measured at the base of the antenna. The expression $160\pi^2 \frac{h^2}{\lambda^2}$ is called the radiation resistance, as it takes the same position in the energy equation as that occupied by R in the case of ohmic losses. The expression shows that the radiation resistance falls rapidly as the wave-length is increased.

Up to the present no satisfactory theory of ground resistance has been developed. The experimental curves of antenna resistance, on account of the decreasing radiation resistance, fall rapidly at first, as the wave-length is increased, and then, as the wave-length is further increased, remain nearly constant if the ground conditions are good, as in the case of a ship's antenna, or again rise nearly in a straight line if the ground conditions are poor. This rise may be very rapid in the case of peculiarly poor grounds. For instance, the resistance of the Bureau of Standards antenna rises from 13 ohms at 800 metres wave-length to 28 ohms at 2000 metres. Great difficulty has been found in explaining this increase of resistance with increasing wave-length, but it is believed that the following explanation is the true one: The antenna system must be looked upon as a condenser, the antenna itself

* Communicated by the Bureau.

being the upper plate and the ground water the lower plate. Between the ground water and the surface there is usually a layer of semi-conducting material which would correspond to a poor dielectric in the case of an ordinary condenser. It is well known that the dielectric losses in imperfect condensers generally increase in proportion to the wave-length of the current employed in the measurement. It is found that by covering the surface of the ground under and around the antenna with a wire net, thus making the net the lower plate of the condenser, the ground losses nearly disappear.

A PRELIMINARY REPORT ON ELECTROLYSIS MITIGATION IN ELYRIA, OHIO.

By Burton McCollum and K. H. Logan.

[ABSTRACT.]

THIS report is based on data furnished the Bureau of Standards by the city of Elyria and the Cleveland, Southwestern & Columbus Railway Company. The data show that the feeding distances of the power-house located a little south of the city limits are long, and, as a consequence, the overall potentials, potential gradients, and potential differences between pipes and rails are too high for safe electrolysis conditions.

The report recommends that the rail gradients be reduced to 0.3 volt per 1000 feet average for 24 hours, which corresponds to maximum value for the 15-minute peak to about 0.75 volt per 1000 feet. To obtain this low gradient economically three changes in the present method of operation are proposed.

A substation should be located at Chestnut, approximately half-way between Elyria and Ridgeville, and the substation at Penfield should take part of the load originating between it and Elyria. The tracks of the Cleveland, Southwestern & Columbus and the Lake Shore Electric Railways should be interconnected at West and Mill Streets, and an insulated return feeder system should be installed to reduce the gradients on Middle Avenue.

Enough copper can be removed from the present positive feeder system after the installation of the Chestnut substation to provide for the return feeders.

The total investment required for the proposed changes is estimated as $34,373. The power saved by the proposed changes

is shown to be more than sufficient to pay all annual charges on the proposed installation and leave a net profit of about $1600 per year. A further advantage of the proposed plan is the provision of 800 kilowatts additional reserve substation capacity and improved operating conditions.

A system of potential wires extending from some central point to the point of lowest potential on the track and to the points of highest potential within the city on each line is recommended.

SPECIAL STUDIES IN ELECTROLYSIS MITIGATION.

3. A REPORT ON CONDITIONS IN SPRINGFIELD, OHIO, WITH INSULATED FEEDER SYSTEM INSTALLED.

By Burton McCollum and G. H. Ahlborn.

THIS report concerning electrolysis conditions in Springfield, Ohio, deals with the electrolysis situation with the completed mitigation systems in operation and the track return much improved.

Before presenting the data taken in the survey the general condition of city and the public utilities which might affect electrolysis are discussed. The insulated return feeder system is described in detail, the description including data on cables and resistance taps and a map of the systems. The permanent pressure wire system installed to obtain overall potential measurements is described in detail.

The cost of railway operation as it is affected by the mitigation system is shown to be slightly greater than it was before any system was installed. This is due to the investment in copper, the power losses being about the same. The cost is less than with the first mitigation system in operation, chiefly because the power losses have been reduced. The annual charges on the feeders are shown in detail.

The methods employed in obtaining the data are discussed and the correction and reduction factors that must be applied to the various sets of readings are given, the data being reduced to average values for the 24-hour and maximum hour periods.

The data were obtained in July and August, 1914, and are discussed under the heads, Potential Differences, Potential Gradients, Overall Potentials, and Stray Currents in Underground Structures. The potential differences between pipes and rails

show that all values are well below one volt for the all-day average, and at only two points do the values for the maximum hour reach one volt. The potential differences between gas and water mains are practically zero, and the lead sheaths are everywhere negative to the other structures and ground. The potential gradients are low on all sections of track, and on all repaired sections not substantially insulated from ground the overall potentials are less than 3 volts for the all-day average values. There were still two or three sections not completely bonded or practically insulated from earth where the drop was over 3 volts. The stray current in the underground structures is practically negligible at all points, that in the gas mains being especially low. There are a few points where tracks lie near each other where local potential differences should be further reduced by cross-ties between such tracks. The potential differences existing in such places are shown and the amount of copper necessary for the cross-ties is stated. In reviewing the above data it is pointed out that the structures are comparatively safe and the results obtained satisfactory.

The data obtained during the summer of 1914 are compared with similar data taken in the survey of the previous winter to determine any effect of frost and lower temperatures. The loads on the interurban lines are about the same during both seasons, but decidedly heavier on the Springfield Railway during the winter. Taking this into consideration, as well as the increased conductivity of the rails in cold weather, it is evident that the potential differences are greater because of the frost, but that the stray currents are reduced.

Recommendations are made concerning improvement in track bonding, precautions that should be taken in the laying of new pipes and repairing old ones, and supervision and inspection by the city officials in order to maintain good electrolysis conditions. It is recommended that the insulated return feeder system be continued in operation and annually inspected, that the sections of track mentioned in the report as in bad condition be repaired, that certain interconnections between tracks be made, and that the pressure wire system now installed be maintained. It is also recommended that no pipe drainage and only limited lead sheath drainage be permitted, that pipe-owning companies install new mains and services so as to pick up as little stray current as

possible, and insert insulating joints in new mains and services where these are in close proximity to railway lines.

The city is urged to adopt 3 volts average for the 24-hour period as the overall voltage limit, except on two lines, where 4 volts may be permitted; to require rebonding of rail joints where their resistance exceeds that of ten feet of rail; to require annual tests and reports of bonding conditions, and to appoint a city expert to determine overall potentials and pass on the above tests and reports.

A METHOD FOR MEASURING EARTH RESISTIVITY.

By Frank Wenner.

[ABSTRACT.]

A KNOWLEDGE of earth resistivity may be of value in determining something of its composition, such, for example, as moisture content, whether or not it contains oil or ore of high conductivity, etc., or in the calculation of damages to pipe systems by the return current of street railway systems. For some of these or other reasons we may wish to determine the resistivity of limited portions of the earth.

For those cases in which we desire the resistivity of a fairly large portion of earth, extending to a considerable depth, or where there are reasons why the measurement should be made without disturbing the portion to be measured, the following method is suggested:

Four holes are made in the earth approximately uniformly spaced in a straight line. The diameter of the holes is not more than 10 per cent. of the distance between them and all extend to approximately the same depth, which is usually that at which we are most concerned with the resistivity. In each hole is placed an electrode which makes electrical contact with the earth only near the bottom. Two of these electrodes serve as current terminals and two as potential terminals in the measurement of the resistance.

Knowing the resistance, the depth of the holes, and the distance between them, we have data from which the effective resistivity in the vicinity can be calculated.

In case a is the distance between the holes, b is the depth of

the holes, ρ is the resistivity, and R the measured resistance, then

$$\rho = \frac{4\pi aR}{1 + \frac{2a}{\sqrt{a^2 + 4b^2}} - \frac{2a}{\sqrt{4a^2 + 4b^2}}} = \frac{4\pi aR}{n} \qquad (1)$$

where n varies between 1 and 2 according to the ratio of the depth of the electrodes to their distance apart. If the holes are not in a straight line or are not of a uniform depth or spacing, the resistivity is easily calculated from the depth of each of the holes and the distance of each from each of the other three.

Concerning the resistance measurements, there is in general no need for a high accuracy. There is, therefore, no reason why we may not use an ammeter for measuring the current and a voltmeter for measuring the resulting difference in potential between the potential terminals, providing no current is drawn from these terminals. As the voltage to be measured is low and the resistance between electrodes and earth high, errors would be introduced if the ammeter-voltmeter method were used in the ordinary way.

The following potentiometer arrangement, using alternating current to obviate the more serious difficulties which might arise on account of polarization with direct current, seems to answer the purpose fairly well. The current terminal or electrodes are connected to a source of alternating voltage of suitable value, and across the line is connected a step-down transformer, the low-voltage side of which is connected to the ends of a slide wire. One of the potential terminals is connected to one end of the slide wire and the other, through a vibration galvanometer, to the adjustable contact on the slide wire. An ammeter is connected into a lead to one of the current and a voltmeter across the ends of the slide wire. On account of the polarization at the current electrodes a variable inductance is connected into one end of the leads, for the purpose of bringing the test current in phase with the voltage of the low side of the transformer.

If, then, adjustments are made so that no current flows through the galvanometer, the position of the sliding contact, the value of the test current, and the voltage across the slide wire are read, we have data from which the resistance R is readily calculated.

From the measured resistance, and the depth and distance between electrodes, a value may be obtained for the effective

resistivity as explained above. The value depends mainly upon the resistivity in the neighborhood of and between the potential electrodes, and very little upon the resistivity at distances from either of these electrodes equal to half the distance between the current electrodes.

So far the method has been used only for determining resistivities in a region very close to the surface, a few metres or less in radius. To measure the effective resistance of a much larger portion of earth extending to a considerable depth, the electrodes would be placed much farther apart. Such a measurement might be of assistance in locating deposits of ore of high conductivity.

INTERFERENCE MEASUREMENT OF WAVE-LENGTHS IN THE IRON SPECTRUM (2851–3701).

By Kewin Burns.

The determination of accurate wave-lengths in the spectra of iron and of other elements has recently been undertaken by the Bureau of Standards. The need for wave-length determinations of great accuracy has long been felt by physicists, chemists, and astronomers. As an example, it is impossible to make a complete spectral analysis of iron, owing to our lack of exact knowledge of the spectra of some elements of the ferrous group. Before any reliable wave-lengths can be obtained there must necessarily be a consistent fundamental system. On account of the irregularities existing in the Rowland system of wave-lengths, an international conference of eminent spectroscopists has recommended the adoption of a new system of wave-lengths based on the length of the red cadmium line as determined by Benoit, Faby, and Perot by direct comparison with the meter. In this system, by means of the interferometer, secondary standards are to be determined in the iron spectrum at intervals of 10A (0.001μ); that is, the wave-length of each standard is to differ by 10 A from the wave-length of its nearest neighbors to the violet and red. The Bureau of Standards has undertaken to do the part of this work for which the present need seems to be the greatest, and this paper presents the first instalment of wave-lengths to be measured here in keeping with the international plan.

The spectrograms upon which this work is based were obtained at Marseilles, in the laboratories of Messrs. Buisson and Faby.

The interferometer plates were quartz disks whose inner surfaces were coated with a semi-transparent film of nickel. The light from the iron arc was focussed on these plates by a quartz lens, and the resulting rings were projected upon the slit of the spectrograph by means of an achromatic lens made of quartz and fluorite. The light passing through the slit was drawn out into a spectrum by means of a 21-inch Rowland grating mounted in parallel light. In this way each line in the iron spectrum is photographed as the diameter of a system of interference rings. By measuring the diameters of these rings the wave-lengths were found by the method of Buisson and Faby. A Michelson cadmium tube furnished the standard red line, the rings from which were photographed before and after each exposure on the iron. Between the limits 2851 A and 3701 A, 131 wave-lengths were measured. Where it was found possible, faint lines as well as strong ones were measured. Throughout the greater part of the region lines were measured at intervals of 10 A or less. The accuracy of the measurements appears to be about one part in two millions; in other words, the wave-lengths are accurate to one five-hundred-millionth of a millimetre.

A Chain Fire-door Screen. Anon. (*Power*, vol. 42, No. 3, July 20, 1915.)—When a furnace door is opened cold air rushes in, chills the highly-heated brickwork and the boiler shell causes contraction of the plate, and lowers the temperature of the combustible gases. To overcome these objectionable features a simple device known as the Wiegand auxiliary chain screen door has been designed. The chain door contains numerous separately hanging strands of small steel chain suspended from a cylinder extending across the top of the furnace door, with the chains hung as close together as possible, forming a continuous sheet, somewhat after the fashion of the common window shade. Opening the door automatically unrolls the chain and covers the opening, preventing to a great extent the escape of heat and checking the entrance of cold air. The screen does not interfere either with cleaning the fires or charging the furnace with fresh fuel.

An idea of the results obtained with the device may be gathered by placing a thermometer ten inches in front of the opening. Without the screen the temperature rises to 400° F. When the opening is covered by the screen the temperature registers 135°, a difference of 265°. With the furnace door closed and the screen rolled up the thermometer shows 110°.

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Iowa State College of Agriculture and Mechanic Arts, General Catalogue, 1915; Bulletins Nos. 33–38. Ames. no date. (From the College.)
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New York Public Service Commission, Second District, Eighth Annual Report, 1914. Albany, 1915. (From the Commission.)
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Philadelphia Maritime Exchange, Fortieth Annual Report. Philadelphia, 1915. (From the Exchange.)

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Temple University, Annual Catalogue, 1915–16. Philadelphia, 1915. From the University.)

Thompson, W. P., and Company, Handbook of Patent Law of All Countries. London, 1915. (From the Company.)

Tokyo Imperial University, Journal of the College of Science, vols. xxxv, art. 8, and xxix, art. 1. Tokyo, 1914. (From the University.)

U. S. Bureau of Mines, Technical Papers 39, 63, 68, 84, 99, 100; Miners' Circulars 11, 15; Bulletins, 17, 20, 24, 27, 28, 29, 31, 32, 33, 34, 35, 40, 51, 39, 71, 72; Third Annual Report, 1913. Washington, 1911–1915. (From the Bureau.)

Universidad Nacional de la Plata, Anuario, No. 6. La Plata, 1915. (From the Universidad.)

University of Missouri, Engineering Experiment Station Series, vol. 1, Nos. 1–3; vol. ii, Nos. 1–3; vol. iii, Nos. 1–3; vol. iv, Nos. 1–4; Series Nos. 14 and 15. Columbia, 1910–1914. (From the University.)

Waltham Water Department, Forty-second Annual Report. Waltham, Mass., 1915. (From the Chief Engineer.)

BOOK NOTICES.

ELECTRICAL INSTRUMENTS IN THEORY AND PRACTICE, by W. H. F. Murdoch, B.Sc., and U. A. Oschwald, B.A. London: Whittaker & Company, 1915. 366 pages, illustrations, 12mo. Price, 10s. 6d.

As a careful technical compilation this book merits sincere commendation. Its scope is well suggested in the title, the emphasis being laid perhaps more upon the theoretical consideration of the various types of electrical measuring instruments. With an introductory historical summary, and after exposition of the subject of damping (so closely allied to the consideration of electrical measuring devices), the various types of instruments are successively treated. A very considerable portion of the book is devoted to electric supply meters, but we suspect that had the work been prepared primarily for the American technical reader rather than for the British, very much less space would have been devoted to electrolytic and other coulomb meters and very much more to watthour meters. The closing chapters are, respectively, on magnetic testing instruments and the "post-office" box. An admirable feature is found in the very complete references embodied directly in the text.

CHARLES PENROSE.

ANALYSIS OF MILK AND MILK PRODUCTS, by Henry Leffmann, M.D. Fourth edition, revised and enlarged. 115 pages, illustrations, 12mo. Philadelphia: P. Blakiston's Sons & Co., 1915. Price, $1.25.

The fourth edition of this work has just come from the press. As a guide for those engaged in the commercial and food-inspection laboratory it is well known and need not be reviewed at length.

It may be interesting, however, to note that in the present edition American investigations form the basis of many important processes, while in the first edition a considerable part of the material was derived from the publications of foreign workers.

HOUSEHOLD CHEMISTRY FOR THE USE OF STUDENTS IN THE HOUSEHOLD ARTS, by Hermann T. Vaulté, Ph.D., F.C.S. Easton, The Chemical Publishing Company, 1915. VI—233 pages. Small 8vo. Price, $1.50.

Though not stated on the title page, the preface indicates that the present issue is not the first edition of this work. The book is especially adapted to students taking a systematic course in the chemistry of food and household procedures. It is not intended as a popular essay. The author points out that household chemistry cannot be properly studied or taught without a good foundation of modern organic chemistry, and gives a comprehensive syllabus thereof for guidance.

The volume contains a large amount of information, both accurate and clearly expressed. Many illustrative experiments are described, and useful tables for conversion of units of different systems of measurement are included.

A capital defect of the book is the lack of an index. This should be remedied in the next edition.

HENRY LEFFMANN.

PUBLICATIONS RECEIVED.

Chemical German.—An introduction to the study of German chemical literature, including rules in nomenclature, exercises for practice, and collection of extracts from writings of German chemists and other scientists, and a vocabulary of German chemical terms and others used in technical literature, by Francis C. Phillips, Professor of Chemistry in the University of Pittsburgh. Second edition. 252 pages, 8vo. Easton, Pa., Chemical Publishing Company, 1915. Price $2.

A Compend of Medical Chemistry, Inorganic and Organic, Including Urinary Analysis, by Henry Leffmann, A.M., M.D., Professor of Chemistry in the Woman's Medical College of Pennsylvania and in the Wagner Free Institute of Science. Sixth edition, revised. 241 pages, illustrations, 12mo. Philadelphia, P. Blakiston's Son & Company, no date. Price, $1.

Canada Department of Mines, Mines Branch: Products and By-products of Coal, by Edgar Stansfield, M.Sc., and F. E. Carter, B.Sc. Dr. Ing. 51 pages, tables, plates, 8vo. Ottawa, Government Printing Bureau, 1915.

Il Modulatore di Corrente del Dr. Francesco Morano, socio corrispondente. Estratto dagli Atti della Pontificia Accademia Romana dei Nuovi Lincei. 8 pages, plates, quarto. Roma, Institute Pio IX, 1915.

Latin American Monetary Systems and Exchange Conditions, by Joseph T. Cosby, Manager, Foreign Department, The National City Bank of New York. 31 pages, 8vo. New York, 1915.

U. S. Bureau of Mines: Bulletin 72, Occurrence of Explosive Gases in Coal Mines, by N. H. Darton. 248 pages, illustrations, plates, maps, 8vo. Technical Paper 83, The Buying and Selling of Ores and Metallurgical Products, by Charles H. Fueton. 42 pages, 8vo. Technical Paper 107, Production of Explosives in the United States during the Calendar Year 1914, with Notes on Coal Mine Accidents Due to Explosives, compiled by A. H. Fay. 16 pages, 8vo. Washington, Government Printing Office, 1915.

U. S. Department of Agriculture: Bulletin 246, Virtrified Brick Pavements for Country Roads, by Vernon M. Peirce. 38 pages, illustrations, plates, 8vo. Bulletin 257, Progress Reports Experiments in Dust Prevention and Road Preservation, 1914. 44 pages, 8vo. Washington, Government Printing Office, 1915.

Protection of the Eye from Harmful Radiation by Crookes's Glasses. (*Proc. Royal Society,* Series B, vol. 89, No. B 610, August 2, 1915.)—In order to protect the eye from damage by the radiation from luminous bodies it is necessary to remove as completely as possible the ultra-violet and infra-red rays, for these, while taking no part in the vision of external objects, do at the same time cause injury to the eye structures that absorb them. The visual rays, when present in excessive amount or when coming from a source in a position to form sharply-focussed images of filaments, etc., on the retina (eclipse blindness), also do harm and should therefore be reduced in intensity by neutral gray glasses. In the case of daylight the modifying glasses should be worn as spectacles; in the case of artificial illuminants they should form globes so as to limit the rays emitted to those useful for vision. For both purposes the glasses recently perfected by Sir William Crookes are ideal. A glass compound, as follows, was found most efficient in removing rays likely to injure the eye: Soda flux, 96.8.; ferrosoferic oxide, 2.85; carbon, 0.35. Its color is pale green, very pleasant to use, and the eye quickly becomes accustomed to the slight coloration. Color matches appear to be little affected by it.

On the Restraining Action of Sugar in Photographic Development. J. MALDIVEY. (*Comptes Rendus,* vol. 161, No. 4, July 26, 1915.)—Sugar added to a developer produces a restraining effect similar to that of the commonly used potassium bromide. The time of development of a normal metol-hydroquinone developer of 100 c.c. was increased from 5 seconds to 5 minutes by the addition of 60 grammes of sugar without fogging the clear parts of the plate or injuring the quality of the black deposit. Smaller quantities of sugar were found to produce correspondingly smaller increments in the time of development. Experiment indicates that this action is the result of a decreased rate of diffusion of the developer through the gelatin as the quantity of sugar is increased.

CURRENT TOPICS.

Gas Blowing Engines at the Steelton Plant of the Pennsylvania Steel Company. ANON. (*Metallurgical and Chemical Engineering*, vol, xiii, No. 8, August, 1915.)—The advance in the design of blast-furnace blowing equipment during the last five years has been very marked. The directions of progress stand out prominently. First, rotative speeds and piston speeds have been doubled; second, complications in valve gearing have been eliminated; and, third, automatic lubrication has been perfected to such an extent that the cost of attendance and repairs has been materially reduced. All three lines of progress are represented in the new gas blowing engines which the Mesta Machine Company recently installed at the plant of the Pennsylvania Steel Company in Steelton, Pa. These engines are the largest ever built in the United States; the gas cylinders are 46 inches in diameter, the air cylinders are 84 inches in diameter, and the stroke is 60 inches.

The modern gas blowing engine is just as reliable as the steam engine, and, in fact, more reliable. It can be started in less time and does not need to be warmed up. The Mesta gas blowing Engine at the Pennsylvania Steel Company's plant can be started and put on the furnace in less than one minute.

Preliminary Experiments on the Effect of Temperature Control on the Yield of Products in the Destructive Distillation of Hardwood. R. C. PALMER. (*Journal of Industrial and Engineering Chemistry*, vol. 7, No. 8, August, 1915.)—It is shown in small scale distillations that a lowering of the temperature of the process and decreasing the speed at which it takes place give marked increases in the yield of alcohol. Also the laboratory methods give much higher yields of acetic acid than those obtained commercially, but this yield is not greatly affected by varying the laboratory methods.

It is now seen that in applying these variations in methods of distilling on a much larger scale a change in the rate of distillation produces practically the same results in the yield of alcohol, while the actual temperature of the reaction is not shown to be of as great importance. If it could be shown that the formation of alcohol in the destructive distillation reaction and its probable secondary decomposition into methane and carbon dioxide in the presence of the hot charcoal is reversible, the increase in alcohol by control of the reaction, allowing an accumulation of the end products, would be easily explained.

If the products after formation are lost by decomposition, the greater stability of alcohol after formation as compared to acetic acid seems evident, since the large retort which probably involves many interreactions gives practically the same yields of alcohol as the small apparatus, while the acid yield is much less than the laboratory yield. Any process apparatus approaching the high laboratory production of acetic acid will probably have to involve some method of preventing the interreactions in the large apparatus.

It is not improbable that still higher yields than those given can be obtained in the commercial plant with the application of temperature control alone. Thoroughly air-seasoned wood would require appreciably less time to enter into the destructive distillation stage, thus giving a better opportunity to lengthen the period of slow reaction. The drying stage would also not require so high a temperature at the end, thus bringing all but the last portion of the reaction into a lower range of temperature.

These tests are considered as a preliminary indication of the results that may be obtained from the interpretation of temperature control. The study of this phase is being continued by larger runs comprising an entire plant. Other phases of directing the destructive distillation reaction of wood to produce maximum yields of products are being made by the United States Forest Products Laboratory.

Shrinkage and Time Effects in Reinforced Concrete. F. R. MCMILLAN. (*The University of Minnesota, Studies in Engineering*, No. 3, March, 1915.)—In the extensive investigations of the properties and behavior of reinforced concrete that have been made in recent years very little has been done in establishing the effects of loads sustained for long periods of time. This seems the more remarkable in view of the fact that a progressive sagging or cracking has been noticed in many structures. That these changes have not received more attention in the past is probably due to the suspicion of poor construction or inadequate design that is usually raised at the suggestion of such behavior, a suspicion unfortunately too often justified.

In the tests cited in this bulletin it has been found that certain changes do take place that are chargeable neither to poor construction nor inadequate design, but rather to the nature of the material itself—its tendency to shrink and yield under load. It is in recognition of the importance of these changes that this bulletin is brought forth at the present time; for, while no attempt is made even to suggest a solution to the problems presented by these shrinkage and time effects, it is felt that the facts presented are of sufficient importance to warrant their publication. With materials and mixtures used in these tests it is safe to predict a shrinkage of from three-fourths to one inch or more in 100 feet when exposed to the ordinary dry air of a heated building. The yielding of the concrete under

compressive stress with time, a phenomenon similar to the yielding of ductile metals when stressed beyond the yield point, is greater as the unit stress is greater and seems to go on indefinitely. In these tests the deformation due to yielding was found to be from three to five times that produced immediately upon the application of the load.

A few of the possible results that may be looked for where these twin changes are in progress are suggested. The production of cracks in floors, ceilings, and partitions, even though in no sense indicating a structural weakness, is an undesirable feature. And in certain places with some types of structures or details cracks might leave the reinforcement accessible to moisture and thus prove a source of danger. Sagging of the structural framework may cause the bending of doors in positions, a feature that is both expensive and annoying. The tilting of columns by the unequal shrinkage in the different floors might be a source of high bending moments and column stress. But of far more importance than these may be mentioned the two following possible effects, both of which might in certain instances be of serious consequence:

First, the continued yielding of the upper fibres of a beam, coupled with the gradual breaking down of the concrete in tension, may result in a progressive destruction of the bond from the centre toward the supports, similar to that occurring with the progessive loading of a beam as shown by Mr. D. A. Abrams (*Bulletin 71, University of Illinois*). Also the drying out incident to the large shrinkage movement may assist in this destruction of the bond.

Second, the possibility of high stresses in the longitudinal steel of compression members seems to be the most important conclusion to be drawn from these tests. The time yielding of the concrete under stress, combined with the excessive shortening due to shrinkage, may result in deformations from five to fifteen times those expected from the ordinary calculations. In columns of the ordinary ratio of vertical steel in which no allowance has been made for spirals the resulting steel stress is probably well within the elastic limit, but in those columns designed on the assumption of large loads being carried by the hooping the steel stresses may approach dangerously near the yield point.

The Largest Hydraulic Motor. ANON. (*Scientific American*, vol. cxiii, No. 8, August 21, 1915.)—One of the striking exhibits to be seen at the Panama-Pacific Exposition is an immense hydraulic turbine motor, rated at 10,000 horse-power, which is in one of the several buildings for a California light and power company, and which is said to be the largest single discharge turbine ever built.

The casing is vertical, about 17 feet in diameter. The butterfly valve which regulates the admission of water to the turbine is 66 inches in diameter and requires a ten-horse-power motor to operate it. This turbine is built on the reaction principle and runs at a speed

of 360 revolutions per minute under a head of 519 feet, and under these conditions from 400 to 465 cubic feet of water pass through the wheel every second. A spider at the centre, operated by the governor, controls the speed by regulating the opening of the guide vanes.

The electric generators installed in the plant are of a capacity of 12,500 kilowatt-volt-ampères, 6000 volts, three-phase, sixty cycles. Two of the above turbines drive each generator.

Joint Committee on Standards for Graphic Presentation. (*Journal of the American Society of Mechanical Engineers*, vol. 37, No. 8, August, 1915.)—As a result of invitations extended by the American Society of Mechanical Engineers, a number of associations of national scope have appointed representatives on a Joint Committee on Standards for Graphic Presentation. The committee is making a study of the methods used in different fields of endeavor for presenting statistical and quantitative data in graphic form. As civilization advances there is being brought to the attention of the average individual a constantly increasing volume of comparative figures and general data of a scientific, technical, and statistical nature. The graphic method permits the presentation of such figures and data with a great saving of time and also with more clearness than otherwise would be obtained. If simple and convenient standards can be found and made generally known, there will be possible a more universal use of graphic methods and a consequent gain to mankind because of the greater speed and accuracy with which complex information may be imparted and interpreted.

Percussive Electric Welding. ANON. (*Machinery* (London), vol. 6, No. 145, July, 1915.)—This method of electric welding was first applied to the welding of aluminum because that metal had given such trouble in soldering, especially when joining small wires. With the substitution of aluminum wire for copper wire which has taken place in the last few years, the need of a good means of joining aluminum has become urgent, and the percussive electric method was developed primarily for this purpose after a thorough investigation of the methods available. Percussive electric welding differs from the resistance method chiefly in the nature of the current used. For resistance electric welding, alternating current is used, whereas for percussive welding direct current is employed. It is possible to weld any two metals, whether alike or different, of high or low melting-points, or of unequal thermal conductivity, with aluminum; the oxide which covers the surface of the pieces welded prevents the metals from flowing together after the ends have been melted in the usual way. Large wires and rods of aluminum can be welded by melting the metal under the oxide film and then suddenly pushing the ends of the pieces together, breaking the oxide film and allowing the clean metal to flow together, but in small wires this practice is not feasible.

The apparatus employed is similar in construction to a pile-driver on a small scale. This is provided with one stationary and one movable wire grip or chuck. This "forge effect" and velocity can be varied independently by a separate adjustment of the length of drop and mass of the moving parts. The electric energy is supplied from a direct-current generator through an electrolytic condenser. At the instant of contact the condenser is discharged and the energy thus concentrated at the point of contact is sufficiently great to produce a perfect weld between the wires. The generation of heat is so localized, so sudden, and so intense that there is no time for an unequal heat conduction through the shanks of the wire, and the ends will be melted and even vaporized, whether the melting-point of the metal is high or low. All combinations of metals or alloys that have been tried will weld together, but the joints will not be permanent for such combinations as aluminum and tin or lead and iron.

Ionization Potentials of Mercury, Cadmium, and Zinc, and the Single- and Many-lined Spectra of These Elements. J. C. MCLENNAN and J. P. HENDERSON. (*Proc. of the Royal Society*, Series A, vol. 91, No. A, 632, August 2, 1915.)—In a paper by Frank and Hertz in the *Physikalische Zeitschrift* these investigators have shown that the minimum energy required to ionize an atom of mercury is that acquired by an electron in passing through a fall of potential of 4.9 volts. These writers have also shown, in a later communication, that when heated mercury vapor is traversed by electrons possessing energy slightly above this amount the vapor is stimulated to the emission of the single spectral line $\lambda = 2536.72$ Å. U. This result constitutes a new and most interesting application of the quantum theory, for it will be seen that in the relation $Ve = hv$, where $h = 6.6 \times 10^{-27}$ erg sec., 4.9 volts is the potential fall which corresponds to the frequency v of the line $\lambda = 2536.75$ Å. U. If the relation just pointed out be applicable generally to all the elements, it follows that, if the vapor of an element can be shown to be capable of exhibiting a single-line spectrum, the frequency of this single spectral line may be used to deduce the minimum amount of energy required to ionize the atoms of that element.

With the object of establishing such a generalization if possible, some experiments were recently made by the writers, and it has been found that the vapors of cadmium and zinc as well as that of mercury can be stimulated to the emission of single-line spectra when traversed by electrons possessing the requisite amount of energy. With cadmium vapor the wave-length of the line constituting this single-line spectrum is $\lambda = 3260.17$ Å. U., while that of the single-line spectrum of zinc vapor is $\lambda = 3075.99$ Å. U. By the quantum theory it follows that the minimum ionizing potentials for cadmium and zinc vapors are, respectively, 3.74 volts and 3.96 volts.

A New Assay Balance. ANON. (*Metallurgical and Chemical Engineering*, vol. xiii, No. 8, August, 1915.)—An assay balance operated like a typewriter is a novel development in scientific instruments. This balance is the invention of Mr. Wilfrid Heusser, of Salt Lake City, Utah. The feature of the instrument that marks a distinct advance in balance construction is the method of handling the weights, placing them on or removing them from the pan hanger. By merely pressing one or more keys which are in front of and outside of the balance case, any weight or combination of weights can be deposited on the pan hanger. The weights themselves consist of perforated disks made of aluminum for the lighter and platinum for the heavier weights, as is usually the case. Normally each disk is carried by one of a series of upright posts with conical tops passing through a perforated horizontal frame which forms a part of the pan hanger. Each of these upright posts is operated by an individual key on a keyboard in front of the balance. By this means all handling of weights is avoided. An analytical balance embodying the Heusser construction as to truss beam and metallic case has also been developed.

The Relation between Uranium and Radium. F. SODDY and A. F. R. HITCHINS. (*Philosophical Magazine*, vol. 30, No. 176, August, 1915.)—The continuation of the measurements on the growth of radium from purified uranium preparations has shown an unmistakable increase in the rate of growth of radium in the case of the preparation containing three kilogrammes of uranium. The growth of radium appears to be proceeding according to the square of the time as theory requires, if ionium is the only long-lived intermediate member of the series. There is thus now for the first time direct experimental evidence that uranium is the ultimate parent of radium. The period of average life of ionium, calculated from this experiment, is about 100,000 years, assuming 2375 years as the period of radium.

An earlier preparation, containing 408 grammes of uranium, gives practically the same value for the period of ionium, calculated on the assumption that ionium was initially absent. The effect of any ionium initially present in the preparations would be to lengthen the period of ionium, but 100,000 years is probably not far from the actual period of average life.

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